International Telecommunication Union

ITU-T

TELECOMMUNICATION
STANDARDIZATION SECTOR
OF ITU

G.695
(11/2009)

SERIES G: TRANSMISSION SYSTEMS AND MEDIA, DIGITAL SYSTEMS AND NETWORKS

Transmission media and optical systems characteristics – Characteristics of optical systems

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Optical interfaces for coarse wavelength division multiplexing applications

Recommendation ITU-T G.695

ITU-T

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Recommendation ITU-T G.695

Optical interfaces for coarse wavelength division multiplexing applications

Summary

Recommendation ITU-T G.695 provides optical parameter values for physical layer interfaces of coarse wavelength division multiplexing (CWDM) applications with up to 16 channels and up to 10 Gbit/s. Applications are defined using two different methods, one using multichannel interface parameters and the other using single-channel interface parameters. Both unidirectional and bidirectional applications are specified.

Source

Recommendation ITU-T G.695 was approved on 13 November 2009 by ITU-T Study Group 15 (2009-2012) under Recommendation ITU-T A.8 procedures.

FOREWORD

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The World Telecommunication Standardization Assembly (WTSA), which meets every four years, establishes the topics for study by the ITU-T study groups which, in turn, produce Recommendations on these topics.

The approval of ITU-T Recommendations is covered by the procedure laid down in WTSA Resolution 1.

In some areas of information technology which fall within ITU-T's purview, the necessary standards are prepared on a collaborative basis with ISO and IEC.

NOTE

In this Recommendation, the expression "Administration" is used for conciseness to indicate both a telecommunication administration and a recognized operating agency.

Compliance with this Recommendation is voluntary. However, the Recommendation may contain certain mandatory provisions (to ensure e.g., interoperability or applicability) and compliance with the Recommendation is achieved when all of these mandatory provisions are met. The words "shall" or some other obligatory language such as "must" and the negative equivalents are used to express requirements. The use of such words does not suggest that compliance with the Recommendation is required of any party.

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As of the date of approval of this Recommendation, ITU had not received notice of intellectual property, protected by patents, which may be required to implement this Recommendation. However, implementers are cautioned that this may not represent the latest information and are therefore strongly urged to consult the TSB patent database at http://www.itu.int/ITU-T/ipr/.

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Optical interfaces for coarse wavelength division multiplexing applications

1 Scope

This Recommendation applies to optical interfaces for coarse wavelength division multiplexing (CWDM) optical line systems for network applications using single-mode optical fibres. This Recommendation defines and provides values for optical interface parameters of physical point-to-point and ring CWDM system applications. Their principal purpose is to enable transversely (multi-vendor) compatible interfaces.

Applications are defined using two different methods, one using multichannel interface parameters and the other using single-channel interface parameters. Both unidirectional and bidirectional applications are specified.

This Recommendation describes optical line systems that include the following features:

– Maximum number of channels: Up to 16.

– Bit-rate of signal channel: Up to NRZ 10G.

The CWDM wavelength grid is provided in [ITU-T G.694.2].

Specifications are organized according to application codes.

In the future, applications enabling full transverse compatibility at both the multichannel and single-channel interface points may be included.

2 References

The following ITU-T Recommendations and other references contain provisions which, through reference in this text, constitute provisions of this Recommendation. At the time of publication, the editions indicated were valid. All Recommendations and other references are subject to revision; users of this Recommendation are therefore encouraged to investigate the possibility of applying the most recent edition of the Recommendations and other references listed below. A list of the currently valid ITU-T Recommendations is regularly published. The reference to a document within this Recommendation does not give it, as a stand-alone document, the status of a Recommendation.

[ITU-T G.652] Recommendation ITU-T G.652 (2005), *Characteristics of a single-mode optical fibre and cable*.

[ITU-T G.653] Recommendation ITU-T G.653 (2006), *Characteristics of a dispersion-shifted single-mode optical fibre and cable*.

[ITU-T G.655] Recommendation ITU-T G.655 (2006), *Characteristics of a non-zero dispersion-shifted single-mode optical fibre and cable*.

[ITU-T G.664] Recommendation ITU-T G.664 (2006), *Optical safety procedures and requirements for optical transport systems*.

[ITU-T G.671] Recommendation ITU-T G.671 (2005), *Transmission characteristics of optical components and subsystems*.

[ITU-T G.691] Recommendation ITU-T G.691 (2006), *Optical interfaces for single channel STM-64 and other SDH systems with optical amplifiers*.

[ITU-T G.692] Recommendation ITU-T G.692 (1998), *Optical interfaces for multichannel systems with optical amplifiers*.

[ITU-T G.694.2] Recommendation ITU-T G.694.2 (2003), *Spectral grids for WDM applications: CWDM wavelength grid*.

[ITU-T G.707] Recommendation ITU-T G.707/Y.1322 (2007), *Network node interface for the synchronous digital hierarchy (SDH)*.

[ITU-T G.709] Recommendation ITU-T G.709/Y.1331 (2003), *Interfaces for the Optical Transport Network (OTN)*.

[ITU-T G.957] Recommendation ITU-T G.957 (2006), *Optical interfaces for equipments and systems relating to the synchronous digital hierarchy*.

[ITU-T G.959.1] Recommendation ITU-T G.959.1 (2006), *Optical transport network physical layer interfaces*.

[IEC 60825-1] IEC 60825-1 (2007), *Safety of laser products – Part 1: Equipment classification and requirements*.

[IEC 60825-2] IEC 60825-2 (2007), *Safety of laser products – Part 2: Safety of optical fibre communication systems (OFCS)*.

3 Definitions

3.1 Terms defined elsewhere

This Recommendation uses the following terms defined in [ITU-T G.671]:

– coarse wavelength division multiplexing (CWDM);
– optical wavelength multiplexer/demultiplexer;
– channel insertion loss;
– channel spacing;
– differential group delay;
– reflectance.

This Recommendation uses the following term defined in [ITU-T G.694.2]:

– Wavelength grid.

This Recommendation uses the following term defined in [ITU-T G.709]:

– Completely standardized OTUk (OTUk).

This Recommendation uses the following terms defined in Recommendation ITU-T G.872:

– Inter-domain interface (IrDI);
– 3R regeneration.

This Recommendation uses the following terms defined in [ITU-T G.957]:

– joint engineering;
– receiver sensitivity;
– transverse compatibility.

This Recommendation uses the following terms defined in [ITU-T G.959.1]:

– minimum equivalent sensitivity;
– optical tributary signal class NRZ 1.25G;
– optical tributary signal class NRZ 2.5G;
– optical tributary signal class NRZ 10G.

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

3R	Reamplification, reshaping and retiming (regeneration)
ALS	Automatic Laser Shutdown
APR	Automatic Power Reduction
APSD	Automatic Power Shutdown
ASE	Amplified Spontaneous Emission
BER	Bit Error Ratio
DGD	Differential Group Delay
EX	Extinction ratio
ffs	for further study
IrDI	Inter-Domain Interface
MPI	Main Path Interface
MPI-R_M	Multichannel Main Path Interface reference point at the CWDM network element aggregate input
MPI-S_M	Multichannel Main Path Interface reference point at the CWDM network element aggregate output
NA	Not Applicable
NE	Network Element
NRZ	Non-Return to Zero
OA	Optical Amplifier
OADM	Optical Add-Drop Multiplexer
OD	Optical Demultiplexer
OM	Optical Multiplexer
ONE	Optical Network Element
OTUk	completely standardized Optical channel Transport Unit – k
PMD	Polarization Mode Dispersion
RP_R	Link reference point at the CWDM network element aggregate input
RP_S	Link reference point at the CWDM network element aggregate output
R_S	Single-channel reference point at the CWDM network element tributary output
S_S	Single-channel reference point at the CWDM network element tributary input
WDM	Wavelength Division Multiplexing

5 Classification of optical interfaces

5.1 Applications

This Recommendation provides the physical layer parameters and values for CWDM multichannel and single-channel interfaces in physical point-to-point and ring applications. CWDM systems can realize cost-effective applications through a combination of uncooled single mode lasers, relaxed laser wavelength selection tolerances and wide passband filters. CWDM systems can be used in transport networks for a variety of clients, services and protocols.

The specification method used in this Recommendation is categorized into two types.

The first one is a "black box" approach, which means that it is not intended to restrict or specify the internal elements and/or the connections between the elements within the black box. There are, however, functional requirements for the black box, the most important being the inclusion of 3R regeneration. This approach enables transverse compatibility at the multichannel points.

The second type is a "black link" approach which means that optical interface parameters for only (single-channel) optical tributary signals are specified. Additional informative descriptions are provided for the fibre link parameters of the multichannel section, such as maximum attenuation, chromatic dispersion and polarization mode dispersion. This approach enables transverse compatibility at the single-channel point using a direct wavelength-multiplexing configuration. However, it does not enable transverse compatibility at the multichannel points. In this approach, the OM and OD are treated as a single set of optical devices and OADMs can be included.

This Recommendation considers non-amplified multichannel interfaces only; however, in the future, amplified interfaces may be considered.

5.2 Reference points

5.2.1 Unidirectional applications

Figure 5-1 shows a set of reference points for multichannel connection (MPI-S_M and MPI-R_M) only, for the use of the "black box" approach. Here the CWDM network element includes an OM and transmitters, or an OD and receivers.

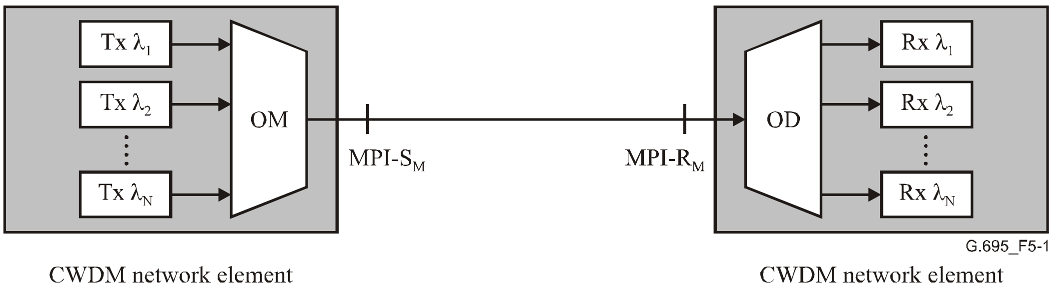

Figure 5-1 – "Black box" approach

Figure 5-2 shows a set of reference points for the linear "black link" approach, for single-channel connection (S_S and R_S) between transmitters (Tx) and receivers (Rx). Here the CWDM network elements include an OM and an OD, which are used as a pair with the opposing element and may also include one or more OADMs.

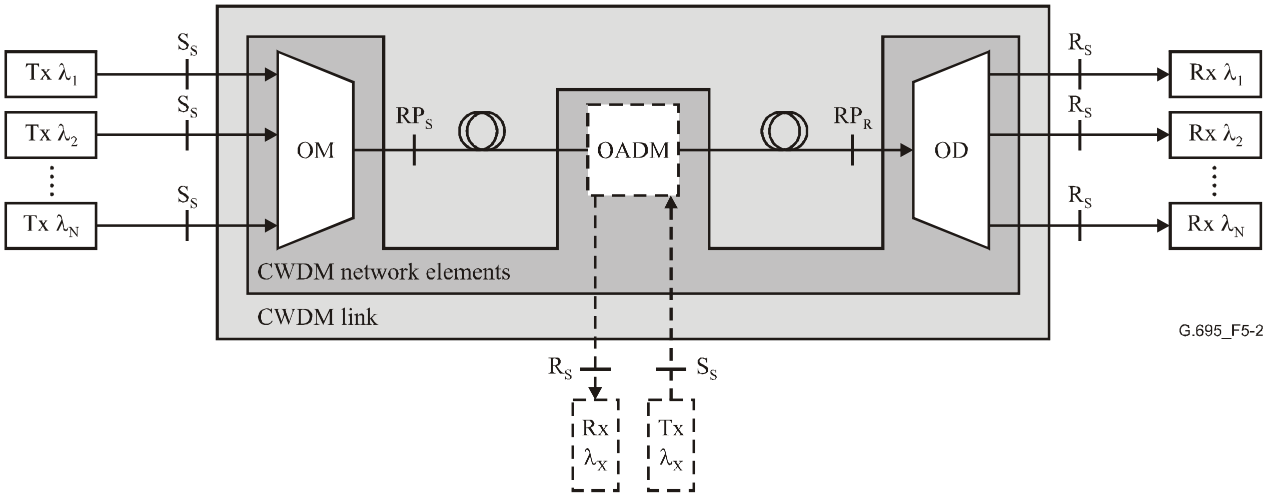

Figure 5-2 – Linear "black link" approach

Figure 5-3 shows a corresponding set of reference points for the ring "black link" approach, for single-channel connection (S_S and R_S) between transmitters (Tx) and receivers (Rx). Here the CWDM network elements include two or more OADMs connected in a ring.

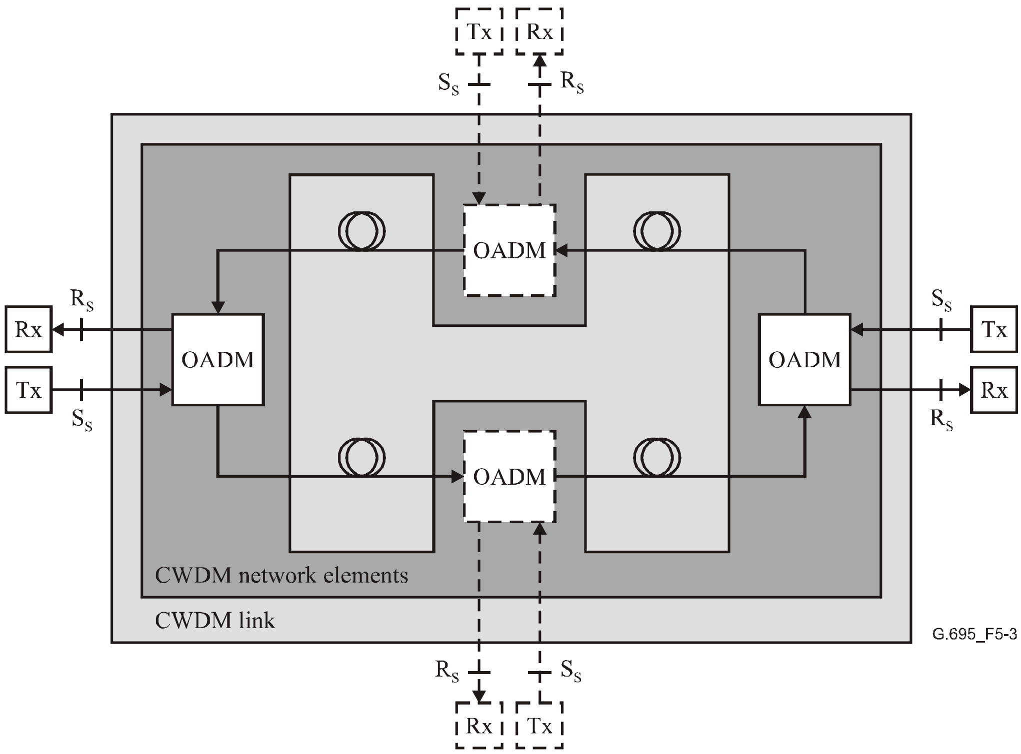

Figure 5-3 – Ring "black link" approach

These reference models do not include any optical amplifiers in the CWDM system. However, in the future, applications including optical amplifiers may be introduced.

The reference points in Figures 5-1, 5-2 and 5-3 are defined as follows:

– S_S is a single-channel reference point at the CWDM network element tributary input;

– R_S is a single-channel reference point at the CWDM network element tributary output;

– MPI-S_M is a multichannel reference point at the CWDM network element aggregate output;

– MPI-R_M is a multichannel reference point at the CWDM network element aggregate input;

– RP_S is a link reference point at the CWDM network element aggregate output;

– RP_R is a link reference point at the CWDM network element aggregate input.

Here, single-channel reference points S_S and R_S are applied to systems for the (linear or ring) "black link" approach where every path from S_S to its corresponding R_S must comply with the parameter values of the application codes in Tables 8-11 to 8-14 and Tables 8-17 to 8-20. Multichannel reference points MPI-S_M and MPI-R_M are applied to systems for the "black box" approach. Link reference points RP_S and RP_R are applied only to systems for the "black link" approach.

Note that MPI-S_M and MPI-R_M are defined to provide normative specifications for optical interfaces. On the other hand, RP_S and RP_R are only defined to provide information for fibre links and not to provide signal characteristics at these points.

5.2.2 Bidirectional applications

Figure 5-4 shows a set of reference points for multichannel connection (MPI-S_M and MPI-R_M) only, for the use of the "black box" approach for single-fibre bidirectional applications. Here the CWDM network element includes an OM/OD, transmitters and receivers.

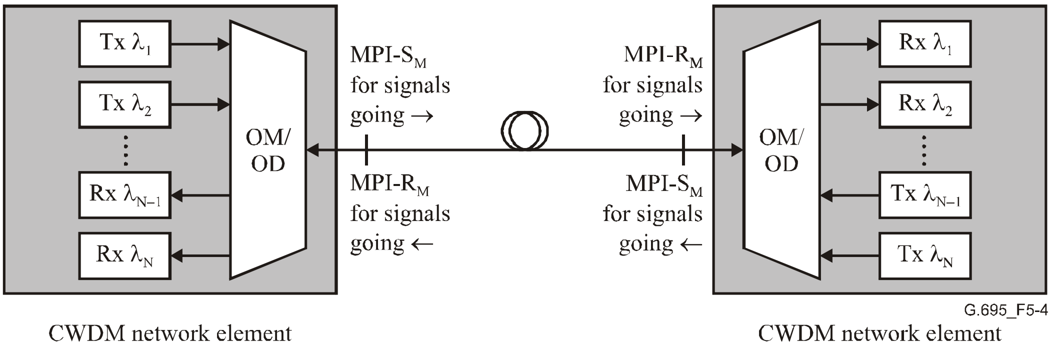

Figure 5-4 – "Black box" approach for bidirectional applications

Figure 5-5 shows a set of reference points for the single-fibre bidirectional linear "black link" approach, for single-channel connection (S_S and R_S) between transmitters (Tx) and receivers (Rx). Here the CWDM network elements include an OM/OD, which is used as a pair with the opposing element and may also include one or more OADMs.

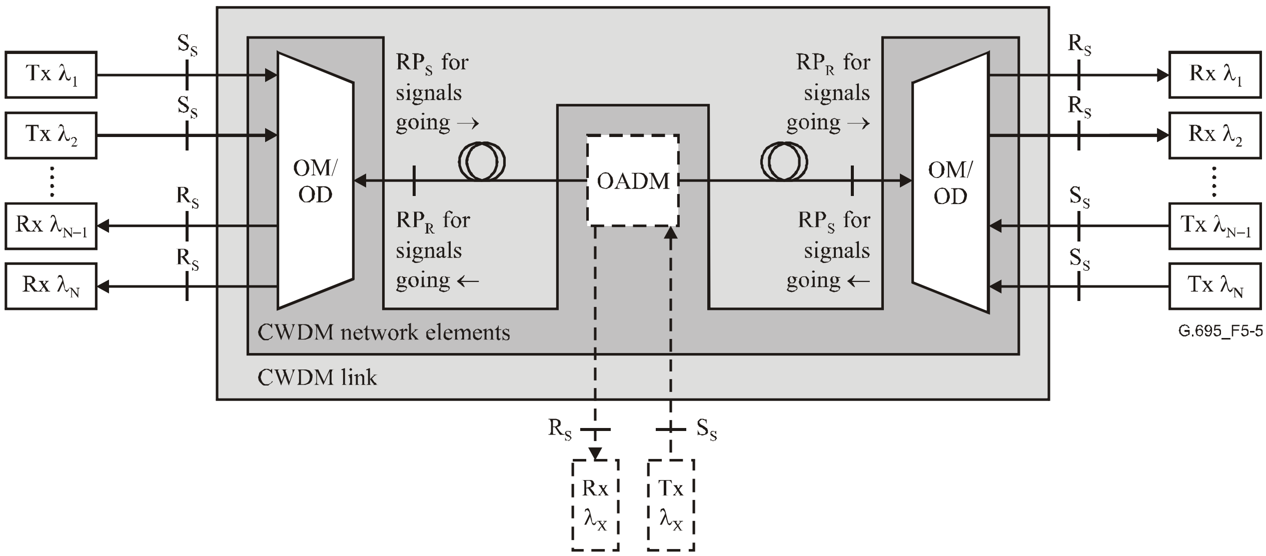

Figure 5-5 – Linear "black link" approach for bidirectional applications

Figure 5-6 shows a corresponding set of reference points for the single-fibre bidirectional ring "black link" approach, for single-channel connection (S_S and R_S) between transmitters (Tx) and receivers (Rx). Here the CWDM network elements include two or more OADMs connected in a ring.

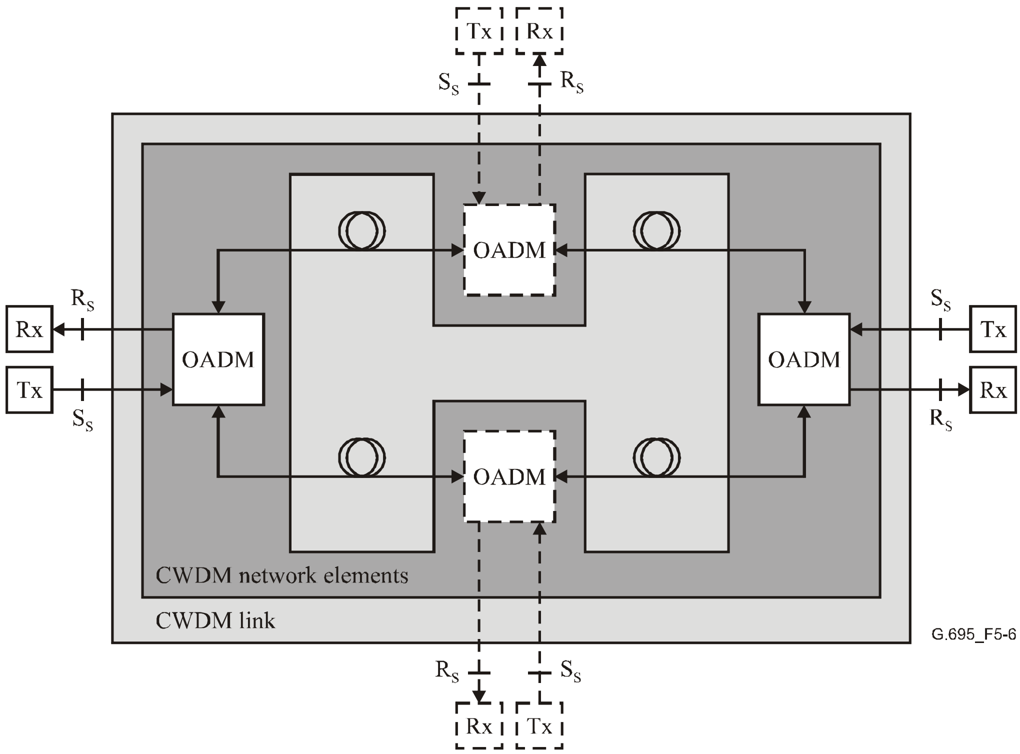

Figure 5-6 – Ring "black link" approach for bidirectional applications

The reference points in Figures 5-4, 5-5 and 5-6 are as defined in 5.2.1.

5.3 Nomenclature

The application code identifies the network, implementation and architectural characteristics of an application.

The application code notation is constructed as follows:

CnWx-ytz

Where:

C is the indicator of CWDM applications.

n is the maximum number of channels supported by the application code.

W is a letter indicating the span distance such as:

- **S** indicating short-haul;
- **L** indicating long-haul.

x is the maximum number of spans allowed within the application code.

NOTE – In the current version of this Recommendation, x = 1 for all applications.

y indicates the highest class of optical tributary signal supported:

- **0** indicating NRZ 1.25G;
- **1** indicating NRZ 2.5G;
- **2** indicating NRZ 10G.

t is a placeholder letter indicating the configuration supported by the application code. In the current version of this Recommendation, the only value used is:

– **D** indicating that the application does not contain any optical amplifiers.

z indicates the fibre types, as follows:

– **1** indicating operation only in the 1310 nm region on ITU-T G.652 fibre;

– **2** indicating operation on ITU-T G.652 fibre;

– **3** indicating operation on ITU-T G.653 fibre;

– **5** indicating operation on ITU-T G.655 fibre.

A bidirectional system is indicated by the addition of the letter **B** at the front of the application code. For CWDM application codes this will be:

B-CnWx-ytz

A system using the "black link" approach is indicated by the addition of the letter **S** at the front of the application code. For CWDM application codes this will be:

S-CnWx-ytz

For some application codes, a suffix is added to the end of the code defined as follows:

– **F** to indicate that this application requires FEC bytes as specified in [ITU-T G.709] to be transmitted.

5.4 Multichannel interfaces at the reference points MPI-S_M and MPI-R_M

The multichannel interfaces described in clauses 5.4.1 and 5.4.2 are intended to enable transverse compatibility. These interfaces may operate on ITU-T G.652, ITU-T G.653 or ITU-T G.655 fibre, simultaneously transporting up to 16 channels, using either NRZ 1.25G, NRZ 2.5G or NRZ 10G optical tributary signals, depending on the particular application code.

Further requirements related to transverse compatibility can be found in clause 6.

Tables 5-1 to 5-5 summarize the multichannel application codes, which are structured according to the nomenclature in clause 5.3.

Table 5-1 – Classification of 4-channel unidirectional multichannel interfaces

Application	**Short-haul (S)**			**Long-haul (L)**		
Type of fibre	G.652	G.653	G.655	G.652	G.653	G.655
Optical tributary signal class NRZ 1.25G	–	–	–	–	–	–
Target distance for class NRZ 1.25G (km)[a)]	–	–	–	–	–	–
Optical tributary signal class NRZ 2.5G	C4S1-1D2	C4S1-1D3	C4S1-1D5	C4L1-1D2	C4L1-1D3	C4L1-1D5
Target distance for class NRZ 2.5G (km)[a)]	37	37	37	69	72	72
Optical tributary signal class NRZ 10G	C4S1-2D1	–	–	–	–	–
Target distance for class NRZ 10G (km)[a)]	10	–	–	–	–	–
[a)] These target distances are for classification and not for specification.						

Table 5-2 – Classification of 4-channel bidirectional multichannel interfaces

Application	Short-haul (S)	Long-haul (L)	
Type of fibre	G.652	G.652	G.653
Optical tributary signal class NRZ 1.25G	–	B-C4L1-0D2	B-C4L1-0D3
Target distance for class NRZ 1.25G (km)[a)]	–	90	90
Optical tributary signal class NRZ 2.5G	–	B-C4L1-1D2	B-C4L1-1D3
Target distance for class NRZ 2.5G (km)[a)]	–	80	83
a) These target distances are for classification and not for specification.			

Table 5-3 – Classification of 8-channel multichannel interfaces

Application	Short-haul (S)	Long-haul (L)	
Type of fibre	G.652	G.652	G.653
Optical tributary signal class NRZ 1.25G	–	B-C8L1-0D2	B-C8L1-0D3
Target distance for class NRZ 1.25G (km)[a)]	–	64	64
Optical tributary signal class NRZ 2.5G	C8S1-1D2 B-C8S1-1D2	C8L1-1D2 B-C8L1-1D2	B-C8L1-1D3
Target distance for class NRZ 2.5G (km)[a)]	27	55	58
Optical tributary signal class NRZ 10G	–	B-C8L1-2D2F	B-C8L1-2D3F
Target distance for class NRZ 10G (km)[a)]	–	55	58
a) These target distances are for classification and not for specification.			

Table 5-4 – Classification of 12-channel multichannel interfaces

Application	Short-haul (S)	Long-haul (L)	
Type of fibre	G.652	G.652	G.653
Optical tributary signal class NRZ 1.25G	–	B-C12L1-0D2	–
Target distance for class NRZ 1.25G (km)[a)]	–	42	–
Optical tributary signal class NRZ 2.5G	–	B-C12L1-1D2	–
Target distance for class NRZ 2.5G (km)[a)]	–	38	–
a) These target distances are for classification and not for specification.			

Table 5-5 – Classification of 16-channel multichannel interfaces

Application	Short-haul (S)	Long-haul (L)	
Type of fibre	G.652	G.652	G.653
Optical tributary signal class NRZ 1.25G	–	–	–
Target distance for class NRZ 1.25G (km)[a)]	–	–	–
Optical tributary signal class NRZ 2.5G	C16S1-1D2 B-C16S1-1D2	C16L1-1D2 B-C16L1-1D2	–
Target distance for class NRZ 2.5G (km)[a)]	20	42	–
a) These target distances are for classification and not for specification.			

5.4.1 Non-amplified multichannel interfaces

The non-amplified multichannel interfaces in this Recommendation are specified in Tables 8-1 to 8-10, 8-15 and 8-16.

5.4.2 Amplified multichannel interfaces

Amplified multichannel interfaces may be introduced into this Recommendation in the future.

5.5 Single-channel interfaces at the reference points S_S and R_S

The single-channel interfaces described in clause 5.5.1 are intended to enable transverse compatibility at the single-channel interfaces at either end of the CWDM link as shown in Figures 5-2, 5-3, 5-5 and 5-6.

Further requirements related to transverse compatibility can be found in clause 6.

Tables 5-6 and 5-7 summarize the single-channel application codes, which are structured according to the nomenclature in clause 5.3. Expected distances for a variety of CWDM network element insertion loss values are provided in Appendix II and information concerning black links containing OADMs is given in Appendix III.

Table 5-6 – Classification of 4-channel multichannel systems with single-channel interfaces

Application	Short-haul (S)	Long-haul (L)
Type of fibre	G.652, G.653, G.655	G.652, G.653, G.655
Optical tributary signal class NRZ 2.5G	S-C4S1-1D2, S-C4S1-1D3, S-C4S1-1D5	S-C4L1-1D2, S-C4L1-1D3, S-C4L1-1D5
Optical tributary signal class NRZ 10G	–	S-C4L1-2D2, S-C4L1-2D2F S-C4L1-2D3, S-C4L1-2D3F S-C4L1-2D5, S-C4L1-2D5F

Table 5-7 – Classification of 8-channel multichannel systems with single-channel interfaces

Application	Short-haul (S)	Long-haul (L)
Type of fibre	G.652, G.653, G.655	G.652, G.653, G.655
Optical tributary signal class NRZ 2.5G	S-C8S1-1D2, S-C8S1-1D3, S-C8S1-1D5	S-C8L1-1D2, S-C8L1-1D3, S-C8L1-1D5
Optical tributary signal class NRZ 10G	–	S-C8L1-2D2, S-C8L1-2D2F S-C8L1-2D3, S-C8L1-2D3F S-C8L1-2D5, S-C8L1-2D5F

5.5.1 Non-amplified multichannel systems with single-channel interfaces

The non-amplified multichannel systems with single-channel interfaces in this Recommendation are specified in Tables 8-11 to 8-14 and Tables 8-17 to 8-20.

5.5.2 Amplified multichannel systems with single-channel interfaces

Amplified multichannel systems with single-channel interfaces may be introduced into this Recommendation in the future.

6 Transverse compatibility

This Recommendation specifies parameters in order to enable transverse (i.e., multivendor) compatibility at multichannel reference points MPI-S_M and MPI-R_M of the "black box" approach CWDM network elements (NEs), and at single-channel reference points S_S and R_S of the "black link" approach CWDM NEs.

The multichannel reference points MPI-S_M and MPI-R_M are intended to interconnect two aggregate interfaces of CWDM NEs, which may be from two different vendors.

The single-channel reference points S_S and R_S are intended to make multiple tributary interfaces of CWDM NEs transversely compatible. In this case, multiple tributary signal transmitters (Tx λ_i) and receivers (Rx λ_i) may be from many different vendors. Note that CWDM NEs (OM and OD) for the "black link" approach are from a single vendor, and considered as a single set of optical devices.

Transverse (multivendor) compatibility is enabled for:

– All multichannel reference points MPI-S_M and MPI-R_M of "black box" approach CWDM NEs having exactly the same application code.

  Interconnection of aggregate interfaces with different application codes is a matter of joint engineering. Care must be taken particularly with respect to critical parameters that must be matched, e.g., MPI-S_M output power, MPI-R_M input power, etc.

– All single-channel reference points S_S and R_S of "black link" approach CWDM NEs having exactly the same application code.

  Co-existence of tributary interfaces with different application codes is a matter of joint engineering. Care must be taken particularly with respect to critical parameters that must be consistent, e.g., S_S output power and R_S input power, S_S bit rate/line coding and R_S bit rate/line coding, etc.

7 Parameter definitions

The parameters in Tables 7-1 and 7-2 are defined at the interface points, and the definitions are provided in the clauses below.

Table 7-1 – Physical layer parameters and values for CWDM applications using the "black box" approach

Parameter	Units	Defined in
General information		
Maximum number of channels	–	7.1.1
Bit rate/line coding of optical tributary signals	–	7.1.2
Maximum bit error ratio	–	7.1.3
Fibre type	–	7.1.4
Interface at point MPI-S_M		
Maximum mean channel output power	dBm	7.2.1
Minimum mean channel output power	dBm	7.2.1
Maximum mean total output power	dBm	7.2.2
Central wavelength	nm	7.2.3
Channel spacing	nm	7.2.4
Maximum central wavelength deviation	nm	7.2.5

Table 7-1 – Physical layer parameters and values for CWDM applications using the "black box" approach

Parameter	Units	Defined in
Minimum channel extinction ratio	dB	7.2.6
Eye mask	–	7.2.7
Optical path from point MPI-S_M to MPI-R_M		
Maximum attenuation	dB	7.3.1
Minimum attenuation	dB	7.3.2
Chromatic dispersion range	ps/nm	7.3.3
Minimum optical return loss at MPI-S_M	dB	7.3.4
Maximum discrete reflectance between MPI-S_M and MPI-R_M	dB	7.3.5
Maximum differential group delay	ps	7.3.6
Interface at point MPI-R_M		
Maximum mean channel input power	dBm	7.4.1
Minimum mean channel input power	dBm	7.4.2
Maximum mean total input power	dBm	7.4.3
Maximum optical path penalty	dB	7.4.4
Minimum equivalent sensitivity	dBm	7.4.7
Maximum reflectance of optical network element	dB	7.4.5

Table 7-2 – Physical layer parameters and values for CWDM applications using the "black link" approach

Parameter	Units	Defined in
General information		
Maximum number of channels	–	7.1.1
Bit rate/line coding of optical tributary signals	–	7.1.2
Maximum bit error ratio	–	7.1.3
Fibre type	–	7.1.4
Interface at point S_S		
Maximum mean channel output power	dBm	7.2.1
Minimum mean channel output power	dBm	7.2.1
Central wavelength	nm	7.2.3
Channel spacing	nm	7.2.4
Maximum central wavelength deviation	nm	7.2.5
Minimum channel extinction ratio	dB	7.2.6
Eye mask	–	7.2.7

Table 7-2 – Physical layer parameters and values for CWDM applications using the "black link" approach

Parameter	Units	Defined in
Optical path from point S_S to R_S		
Maximum channel insertion loss	dB	7.5.1
Minimum channel insertion loss	dB	7.5.1
Chromatic dispersion range	ps/nm	7.3.3
Minimum optical return loss at S_S	dB	7.3.4
Maximum discrete reflectance between S_S and R_S	dB	7.3.5
Maximum differential group delay	ps	7.3.6
Maximum inter-channel crosstalk at R_s	dB	7.5.2
Maximum interferometric crosstalk at R_s	dB	7.5.3
Interface at point R_S		
Maximum mean channel input power	dBm	7.4.1
Receiver sensitivity	dBm	7.4.6
Maximum optical path penalty	dB	7.4.4
Maximum reflectance of receiver	dB	7.4.5

7.1 General information

7.1.1 Maximum number of channels

The maximum number of optical channels that may be simultaneously present at an interface.

For bidirectional applications, the maximum number of channels is expressed in the form n/2 + n/2 where n is the maximum number of channels supported by the application code and n/2 is the number of channels in each direction.

It should be noted that, if it is desired to be able to upgrade a link with a certain maximum channel count to a configuration with a higher maximum channel count, then the set of parameter values specified for the higher channel count application code should be met for the initial link.

As an example, a system designed according to a 4-channel application code cannot be upgraded to an 8-channel system. Such an option should be implemented by under-equipping an 8-channel system and using the set of parameter values for an 8-channel application code.

7.1.2 Bit rate/line coding of optical tributary signals

Optical tributary signal class NRZ 1.25G applies to continuous digital signals with non-return to zero line coding, from nominally 622 Mbit/s to nominally 1.25 Gbit/s. Optical tributary signal class NRZ 2.5G applies to continuous digital signals with non-return to zero line coding, from nominally 622 Mbit/s to nominally 2.67 Gbit/s. Optical tributary signal class NRZ 10G applies to continuous digital signals with non-return to zero line coding, from nominally 2.4 Gbit/s to nominally 10.76 Gbit/s. Optical tributary signal class NRZ 10G includes a signal with STM-64 bit rate according to [ITU-T G.707], OTU2 bit rate according to [ITU-T G.709] and OTL3.4 bit rate (OTU3 striped across four physical lanes) according to [ITU-T G.709].

7.1.3 Maximum bit error ratio

The parameters are specified relative to an optical section design objective of a bit error ratio (BER) not worse than the value specified by the application code. This value applies to each optical channel under the extreme case of optical path attenuation and dispersion conditions in each application. The possible effect on the definition of this parameter due to the presence of forward error correction (e.g., in an OTUk) has not been considered in the present version of this Recommendation.

7.1.4 Fibre type

Single mode optical fibre types are chosen from those defined in [ITU-T G.652], [ITU-T G.653] and [ITU-T G.655].

7.2 Interface at point MPI-S_M or S_S

7.2.1 Maximum and minimum mean channel output power

The mean launched power of each optical channel at reference point MPI-S_M or S_S is the average power of a pseudo-random data sequence coupled into the fibre or the CWDM link. It is given as a range (maximum and minimum) to allow for some cost optimization and to cover allowances for operation under the standard operating conditions, connector degradations, measurement tolerances and aging effects.

7.2.2 Maximum mean total output power

The maximum value of the mean launched optical power at point MPI-S_M.

NOTE – Optical safety aspects have been considered in determining the values given in this Recommendation, since it is desirable to avoid the need for automatic power reduction (APR), automatic power shutdown (APSD), or automatic laser shutdown (ALS) procedures, for cost reasons.

7.2.3 Central wavelength

The nominal single-channel wavelengths on which the digital coded information of the particular optical channels are modulated by use of the NRZ line code (as defined in [ITU-T G.957] and [ITU-T G.691]).

The central wavelengths are based on the wavelength grid given in [ITU-T G.694.2]. The allowed central wavelengths for the multichannel CWDM network element are specified in Tables 8-1 to 8-20.

Note that the value of "c" (speed of light in a vacuum) that should be used for converting between frequency and wavelength is 2.99792458×10^8 m/s.

7.2.4 Channel spacing

The nominal difference in wavelength between two adjacent channels. All possible tolerances of actual wavelengths are considered in clause 7.2.5.

7.2.5 Maximum central wavelength deviation

The difference between the nominal central wavelength and the actual central wavelength. The central wavelength deviation is determined mainly by two factors. First, the laser manufacturer is allowed a wavelength variation around the nominal wavelength in order to achieve a higher yield and/or relax fabrication tolerances. Second, the use of uncooled lasers will cause the wavelength to change with temperature within the specified temperature range of the laser.

Also included in the central wavelength deviation are all the processes that affect the instantaneous value of the source central wavelength over a measurement interval appropriate to the channel bit rate. These processes include source chirp, information bandwidth, broadening due to self-phase modulation, and effects due to aging.

Maximum central wavelength deviation in CWDM point-to-point systems is provided in Tables 8-1 to 8-20.

7.2.6 Minimum channel extinction ratio

The extinction ratio (EX) is defined in Rec. ITU-T G.693 for a single-channel parameter, as:

$$EX = 10 \times \log_{10}(A/B)$$

In the above definition of EX, A is the average optical power level at the centre of a logical "1" and B is the average optical power level at the centre of a logical "0". The convention adopted for optical logic levels is:

– emission of light for a logical "1";

– no emission for a logical "0".

The minimum channel extinction ratio is not required to be met in the presence of a fourth-order Bessel-Thomson filter.

For multichannel interfaces, two alternative methods can be used for the verification of this parameter as in [ITU-T G.959.1]:

– Method A can be used when single-channel reference points are accessible at the transmit end of the link for verification. For this method, the procedures described in [ITU-T G.957] and [ITU-T G.691] are used. The configuration for this method is contained in Annex A of [ITU-T G.959.1];

– Method B employs a reference optical bandpass filter to isolate the individual transmitted signal. The characteristics of the reference optical bandpass filter are contained in Annex B of [ITU-T G.959.1].

7.2.7 Eye mask

The definition and filter limits for this parameter are found in [ITU-T G.959.1]. This definition can be directly applied to single-channel interfaces of the "black link" approach. In the case of the multichannel interfaces of the "black box" approach, two alternative methods can be used as in [ITU-T G.959.1]:

– Method A can be used when single-channel reference points are accessible at the transmit end of the link for verification. For this method, the procedures described in [ITU-T G.957] and [ITU-T G.691] are used. The configuration for this method is contained in Annex A of [ITU-T G.959.1];

– Method B employs a reference optical bandpass filter to isolate the individual transmitted signals, followed by a reference receiver. The characteristics of the reference optical bandpass filter and the reference receiver are contained in Annex B of [ITU-T G.959.1].

7.3 Common optical path parameters (single span) from point MPI-S_M to MPI-R_M, or from S_S to R_S

7.3.1 Maximum attenuation

The maximum path attenuation, for all wavelengths used by the application, where the system in question operates under end-of-life conditions at a BER of 10^{-12} (or as given by the application code), under worst-case transmit-side signal and dispersion. The definition of effects included in the maximum attenuation is given in clause 6.3.1 of [ITU-T G.691].

The target distances for each application are based on the set of assumed maximum attenuation coefficients found in Appendix I. The values given represent installed fibre loss (including splices and cable margin). It should be noted that this method gives a theoretical value. Connector and splice losses as well as losses due to bending or optical monitoring, which can be present in practical implementations, may lead to other distances.

7.3.2 Minimum attenuation

The minimum path attenuation that allows the system in question, operating under worst-case transmit conditions to achieve a BER no worse than 10^{-12} (or as given by the application code).

7.3.3 Chromatic dispersion range

This parameter defines the range of values of the optical path chromatic dispersion that the system shall be able to tolerate. The limits are considered worst-case dispersion values. The worst-case approach on this parameter is intended to give some margins on a sensitive parameter, as well as making it possible to stretch the transmission distances for low-loss fibre plants.

The process used to derive the limits of the chromatic dispersion range, contained in Tables 8-1 to 8-20 was:

– Estimate the maximum link length supported by each application code from:
  - for black box applications, the maximum attenuation divided by the highest value of the minimum attenuation coefficient from Table I.1 across the range of wavelength channels specified for that application code;
  - for black link applications, the maximum attenuation minus an allowance for the loss of an OM/OD pair, divided by the highest value of the minimum attenuation coefficient from Table I.1 across the range of wavelength channels specified for that application code.
– Estimate the maximum dispersion of this fibre length for the highest (absolute value) dispersion channel.
– Where the dispersion values obtained by this method were considered to be higher than is feasible for current cost-effective optical transmitters, the dispersion values were reduced in accordance with current technology capability (so these applications may be dispersion-limited, e.g., S-C4L1-1D2, whereas the others are loss-limited, e.g., C4S1-1D2).

In this Recommendation, the per channel chromatic dispersion range is specified corresponding to a single maximum dispersion limited distance across the block of channels specified for each application code multiplied by the dispersion coefficient given in Table I.2. As a result of this approach, the dispersion limit at the channel with the highest dispersion coefficient is a rounded value, whereas the dispersion limit of the other channels is derived from this rounded value and the chromatic dispersion coefficients found in Table I.2.

The allowed optical path penalty considers all deterministic effects due to chromatic dispersion as well as the penalty due to the maximum differential group delay.

7.3.4 Minimum optical return loss at MPI-S_M or S_S

Reflections are caused by refractive index discontinuities along the optical path. If not controlled, they can degrade system performance through their disturbing effect on the operation of the optical source, or through multiple reflections which lead to interferometric noise at the receiver. Reflections from the optical path are controlled by specifying the:

– minimum optical return loss of the cable plant at the source reference point (i.e., MPI-S_M, S_S), including any connectors; and
– maximum discrete reflectance between source reference points (i.e., MPI-S_M, S_S) and receive reference points (i.e., MPI-R_M, R_S).

Reflectance denotes the reflection from any single discrete reflection point, whereas the optical return loss is the ratio of the incident optical power to the total returned optical power from the entire fibre including both discrete reflections and distributed backscattering such as Rayleigh scattering.

Measurement methods for reflections are described in Appendix I of [ITU-T G.957]. For the purpose of reflectance and return loss measurements, points S_S and R_S are assumed to coincide with the endface of each connector plug. It is recognized that this does not include the actual reflection performance of the respective connectors in the operational system. These reflections are assumed to have the nominal value of reflection for the specific type of connectors used.

7.3.5 Maximum discrete reflectance between MPI-S_M and MPI-R_M or between S_S and R_S

Optical reflectance is defined to be the ratio of the reflected optical power present at a point, to the optical power incident to that point. Control of reflections is discussed extensively in [ITU-T G.957]. The maximum number of connectors or other discrete reflection points which may be included in the optical path (e.g., for distribution frames, or WDM components) must be such as to allow the specified overall optical return loss to be achieved. If this cannot be done using connectors meeting the maximum discrete reflections cited in the tables of clause 8, then connectors having better reflection performance must be employed. Alternatively, the number of connectors must be reduced. It also may be necessary to limit the number of connectors or to use connectors having improved reflectance performance in order to avoid unacceptable impairments due to multiple reflections.

In the tables of clause 8, the value of maximum discrete reflectance between source reference points and receive reference points is intended to minimize the effects of multiple reflections (e.g., interferometric noise). The value for maximum receiver reflectance is chosen to ensure acceptable penalties due to multiple reflections for all likely system configurations involving multiple connectors, etc. Systems employing fewer or higher performance connectors produce fewer multiple reflections and consequently are able to tolerate receivers exhibiting higher reflectance.

7.3.6 Maximum differential group delay

Differential group delay (DGD) is the time difference between the fractions of a pulse that are transmitted in the two principal states of polarization of an optical signal. For distances greater than several kilometres, and assuming random (strong) polarization mode coupling, DGD in a fibre can be statistically modelled as having a Maxwellian distribution.

In this Recommendation, the maximum differential group delay is defined to be the value of DGD that the system must tolerate with a maximum sensitivity degradation of 1 dB.

Due to the statistical nature of polarization mode dispersion (PMD), the relationship between maximum DGD and mean DGD can only be defined probabilistically. The probability of the instantaneous DGD exceeding any given value can be inferred from its Maxwellian statistics. Therefore, if we know the maximum DGD that the system can tolerate, we can derive the equivalent mean DGD by dividing by the ratio of maximum to mean that corresponds to an acceptable probability. Some example ratios are given below in Table 7-3.

Table 7-3 – DGD means and probabilities

Ratio of maximum to mean	Probability of exceeding maximum
3.0	4.2×10^{-5}
3.5	7.7×10^{-7}
4.0	7.4×10^{-9}

7.4 Interface at point MPI-R_M or R_S

7.4.1 Maximum mean channel input power

The maximum acceptable value of the average received channel power at point MPI-R_M or R_S to achieve the specified maximum BER of the application code.

7.4.2 Minimum mean channel input power

The minimum acceptable value of the average received channel power at point MPI-R_M or R_S. The minimum mean channel input power is the minimum mean channel output power minus the maximum attenuation of the application.

NOTE – The minimum mean channel input power at MPI-R_M must be higher than the minimum equivalent sensitivity by the value of the maximum optical path penalty.

7.4.3 Maximum mean total input power

The maximum acceptable total input power at point MPI-R_M.

7.4.4 Maximum optical path penalty

The path penalty is the apparent reduction of receiver sensitivity (or equivalent sensitivity in the case of the "black box" approach) due to distortion of the signal waveform during its transmission over the path. It is manifested as a shift of the system's BER curves towards higher input power levels. This corresponds to a positive path penalty. Negative path penalties may exist under some circumstances, but should be small (a negative path penalty indicates that a less than perfect transmitter eye has been partially improved by the path dependent distortions). Ideally, the BER curves should be translated only, but shape variations are not uncommon, and may indicate the emergence of BER floors. Since the path penalty is a change in the receiver's sensitivity, it is measured at a BER level of 10^{-12}.

In the "black box" approach (where minimum channel input power is specified), the maximum optical path penalty is equal to the difference between the minimum mean channel input power at MPI-R_M and the minimum equivalent sensitivity.

For the applications defined in this Recommendation, the path penalties are limited to a maximum of 1.5 dB for short-haul systems and 2.5 dB for long-haul systems. These limits are higher than in other Recommendations due to the additional penalty caused by optical crosstalk.

In the future, systems employing dispersion accommodation techniques based on pre-distortion of the signal at the transmitter may be introduced. In this case, the path penalty in the above sense can only be defined between points with undistorted signals. These points, however, do not coincide with the main path interfaces, and may thus not even be accessible. The definition of path penalty for this case is for further study.

The average value of the random dispersion penalties due to PMD is included in the allowed path penalty. In this respect, the transmitter/receiver combination is required to tolerate an actual DGD of 0.3 bit period with a maximum sensitivity degradation of 1 dB (with 50% of optical power in each principal state of polarization). For a well-designed receiver, this corresponds to a penalty of 0.1-0.2 dB for a DGD of 0.1 bit period. The actual DGD that may be encountered in operation is a randomly varying fibre/cable property, and cannot be specified in this Recommendation. This subject is further discussed in Appendix I of [ITU-T G.691].

Note that a signal-to-noise ratio reduction due to optical amplification is not considered a path penalty.

For applications using the "black link" approach, path penalty includes crosstalk penalty.

For multichannel interfaces, two alternative methods can be used for the verification of this parameter:

– Method A can be used when single-channel reference points are accessible at the receive end of the link for verification. For this method, the procedures described in [ITU-T G.957] and [ITU-T G.691] are used. The configuration for this method is contained in Annex A of [ITU-T G.959.1].
– Method B employs a reference optical bandpass filter to isolate the individual transmitted signals, followed by a reference receiver. The characteristics of the reference optical bandpass filter and the reference receiver are contained in Annex B of [ITU-T G.959.1].

NOTE – The optical path penalty observed in the reference receiver may not be exactly the same as actually experienced in the receiving equipment, depending on the design implementation.

7.4.5 Maximum reflectance of CWDM network element or receiver

Reflections from the equipment back into the cable plant, or from the receiver back into the CWDM link, are specified by the maximum permissible reflectance of equipment or the receiver measured at reference point MPI-R_M or at R_S, respectively. Optical reflectance is defined in [ITU-T G.671].

7.4.6 Receiver sensitivity

Receiver sensitivity is defined as the minimum value of average received power at point R_S to achieve a 10^{-12} BER. This must be met with a transmitter with worst-case values of transmitter eye mask, extinction ratio, optical return loss at point S_S, receiver connector degradations and measurement tolerances. The receiver sensitivity does not have to be met in the presence of dispersion, reflections from the optical path or optical crosstalk; these effects are specified separately in the allocation of maximum optical path penalty.

NOTE – The receiver sensitivity does not have to be met in the presence of transmitter jitter in excess of the appropriate jitter generation limit (e.g., Rec. ITU-T G.8251 for OTN optical tributary signals).

Aging effects are not specified separately since they are typically a matter between a network operator and an equipment manufacturer.

7.4.7 Minimum equivalent sensitivity

This is the minimum sensitivity that would be required of a receiver placed at MPI-R_M to achieve the specified maximum BER of the application code if all except one of the channels were to be removed (with an ideal loss-less filter) at point MPI-R_M. This would have to be met with a transmitter with worst-case values of transmitter eye mask, extinction ratio, optical return loss at point MPI-S_M, connector degradations, transmit-side crosstalk, optical amplifier noise and measurement tolerances. This sensitivity would not have to be met in the presence of dispersion, non-linearity, reflections from the optical path or crosstalk; these effects are specified separately in the allocation of maximum optical path penalty.

NOTE 1 – The minimum mean channel input power at MPI-R_M must be higher than the minimum equivalent sensitivity by the value of the maximum optical path penalty.

NOTE 2 – The receiver sensitivity does not have to be met in the presence of transmitter jitter in excess of the appropriate jitter generation limit (e.g., Rec. ITU-T G.8251 for OTN optical tributary signals).

Aging effects are not specified separately. Worst-case, end-of-life values are specified.

7.5 Additional parameters for the optical path from S_S to R_S

7.5.1 Minimum and maximum channel insertion loss

Channel insertion loss is defined in [ITU-T G.671].

7.5.2 Maximum inter-channel crosstalk

This parameter places a requirement on the isolation of a link conforming to the "black link" approach such that, under the worst-case operating conditions, the inter-channel crosstalk at any reference point R_S is less than the maximum inter-channel crosstalk value.

Inter-channel crosstalk is defined as the ratio of total power in all of the disturbing channels to that in the wanted channel, where the wanted and disturbing channels are at different wavelengths.

Specifically, the isolation of the link shall be greater than the amount required to ensure that when any channel is operating at the minimum mean output power at point S_S and all of the others are at the maximum mean output power, then the inter-channel crosstalk at the corresponding point R_S is less than the maximum inter-channel crosstalk value.

7.5.3 Maximum interferometric crosstalk

This parameter places a requirement on the isolation of a link conforming to the "black link" approach such that, under the worst-case operating conditions, the interferometric crosstalk at any reference point R_S is less than the maximum interferometric crosstalk value.

Interferometric crosstalk is defined as the ratio of the disturbing power to the wanted power within a single-channel, where the disturbing power is the power (not including ASE) within the optical channel that would remain if the wanted signal were removed from the link while leaving all of the other link conditions the same.

Specifically, the isolation of the link shall be greater than the amount required to ensure that when any channel is operating at the minimum mean output power at point S_S and all of the others are at the maximum mean output power, then the interferometric crosstalk at the corresponding point R_S is less than the maximum interferometric crosstalk value.

8 Parameter values

The physical layer parameters and values for multichannel interfaces, for "black box" systems, are given in Tables 8-1 to 8-10 for NRZ 2.5G applications and in Tables 8-15 to 8-16 for NRZ 10G applications.

The physical layer parameters and values for single-channel interfaces, for "black link" systems, are given in Tables 8-11 to 8-14 for NRZ 2.5G applications and in Tables 8-17 to 8-20 for NRZ 10G applications.

Table 8-1 – Physical layer parameters and values for multichannel interfaces for 4-channel NRZ 2.5G short-haul black box applications

Parameter	Units	C4S1-1D2	C4S1-1D3	C4S1-1D5
General information				
Maximum number of channels	–	4		
Bit rate/line coding of optical tributary signals	–	NRZ 2.5G		
Maximum bit error ratio	–	10^{-12}		
Fibre type	–	G.652	G.653	G.655
Interface at point MPI-S_M				
Maximum mean channel output power	dBm	+4.5		
Minimum mean channel output power	dBm	–3		
Maximum mean total output power	dBm	+10.5		
Central wavelength	nm	1511 + 20 m, m = 0 to 3		
Channel spacing	nm	20		
Maximum central wavelength deviation (Note)	nm	±6.5		
Minimum channel extinction ratio	dB	8.2		
Eye mask	–	STM-16 per G.957		
Optical path (single span) from point MPI-S_M to MPI-R_M				
Maximum attenuation	dB	10.5		
Minimum attenuation	dB	4		
Chromatic dispersion range				
– 1511 nm channel	ps/nm	0 to +719	–250 to +39	0 to +323
– 1531 nm channel	ps/nm	0 to +775	–169 to +83	0 to +371
– 1551 nm channel	ps/nm	0 to +833	–124 to +128	0 to +420
– 1571 nm channel	ps/nm	0 to +890	–79 to +177	0 to +470
Minimum optical return loss at MPI-S_M	dB	24		
Maximum discrete reflectance between MPI-S_M and MPI-R_M	dB	–27		
Maximum differential group delay	ps	120		
Interface at point MPI-R_M				
Maximum mean channel input power	dBm	+0.5		
Minimum mean channel input power	dBm	–13.5		
Maximum mean total input power	dBm	+6.5		
Maximum optical path penalty	dB	1.5		
Minimum equivalent sensitivity	dBm	–15		
Maximum reflectance of optical network element	dB	–27		
NOTE – A system with ±7 nm maximum central wavelength deviation which is compliant with all other ITU-T G.695 parameter values of the relevant application code is transversely compatible for any applications covered by that code, except that it does not provide transverse compatibility with a ±6.5 nm system without joint engineering.				

Table 8-2 – Physical layer parameters and values for multichannel interfaces for 4-channel NRZ 2.5G long-haul black box applications

Parameter	Units	C4L1-1D2	C4L1-1D3	C4L1-1D5
General information				
Maximum number of channels	–	4		
Bit rate/line coding of optical tributary signals	–	NRZ 2.5G		
Maximum bit error ratio	–	10^{-12}		
Fibre type	–	G.652	G.653	G.655
Interface at point MPI-S_M				
Maximum mean channel output power	dBm	+4.5		
Minimum mean channel output power	dBm	−3		
Maximum mean total output power	dBm	+10.5		
Central wavelength	nm	1511 + 20 m, m = 0 to 3		
Channel spacing	nm	20		
Maximum central wavelength deviation (Note)	nm	±6.5		
Minimum channel extinction ratio	dB	8.2		
Eye mask	–	STM-16 per G.957		
Optical path (single span) from point MPI-S_M to MPI-R_M				
Maximum attenuation	dB	19.5	20.5	20
Minimum attenuation	dB	13		
Chromatic dispersion range				
– 1511 nm channel	ps/nm	0 to +1332	–490 to +77	0 to +618
– 1531 nm channel	ps/nm	0 to +1437	–331 to +164	0 to +711
– 1551 nm channel	ps/nm	0 to +1544	–242 to +251	0 to +805
– 1571 nm channel	ps/nm	0 to +1650	–155 to +347	0 to +900
Minimum optical return loss at MPI-S_M	dB	24		
Maximum discrete reflectance between MPI-S_M and MPI-R_M	dB	−27		
Maximum differential group delay	ps	120		
Interface at point MPI-R_M				
Maximum mean channel input power	dBm	−8.5		
Minimum mean channel input power	dBm	−22.5	−23.5	−23
Maximum mean total input power	dBm	−2.5		
Maximum optical path penalty	dB	2.5	1.5	2
Minimum equivalent sensitivity	dBm	−25		
Maximum reflectance of optical network element	dB	−27		

NOTE – A system with ±7 nm maximum central wavelength deviation which is compliant with all other ITU-T G.695 parameter values of the relevant application code is transversely compatible for any applications covered by that code, except that it does not provide transverse compatibility with a ±6.5 nm system without joint engineering.

Table 8-3 – Physical layer parameters and values for multichannel interfaces for 4-channel NRZ 1.25G and NRZ 2.5G bidirectional long-haul black box applications

Parameter	Units	B-C4L1-0D2	B-C4L1-0D3	B-C4L1-1D2	B-C4L1-1D3
General information					
Maximum number of channels	–	2 + 2	2 + 2	2 + 2	2 + 2
Bit rate/line coding of optical tributary signals	–	NRZ 1.25G	NRZ 1.25G	NRZ 2.5G	NRZ 2.5G
Maximum bit error ratio	–	10^{-12}	10^{-12}	10^{-12}	10^{-12}
Fibre type	–	G.652	G.653	G.652	G.653
Interface at point MPI-S_M					
Maximum mean channel output power	dBm	+5[b)]	+5[b)]	+5[b)]	+5[b)]
Minimum mean channel output power	dBm	0[b)]	0[b)]	0[b)]	+0[b)]
Maximum mean total output power	dBm	+8	+8	+8	+8
Central wavelength	nm	1511 + 20 m, m = 0 to 3	1511 + 20 m, m = 0 to 3	1511 + 20 m, m = 0 to 3	1511 + 20 m, m = 0 to 3
Channel spacing	nm	20	20	20	20
Maximum central wavelength deviation[a)]	nm	±6.5	±6.5	±6.5	±6.5
Minimum channel extinction ratio	dB	8.2	8.2	8.2	8.2
Eye mask	–	STM-4 per G.957	STM-4 per G.957	STM-16 per G.957	STM-16 per G.957
Optical path (single span) from point MPI-S_M to MPI-R_M					
Maximum attenuation	dB	25.5	25.5	22.5	23.5
Minimum attenuation	dB	12	12	12	12
Chromatic dispersion range					
– 1511 nm channel	ps/nm	0 to +1735	–610 to +95	0 to +1533	–560 to +88
– 1531 nm channel	ps/nm	0 to +1872	–412 to +204	0 to +1654	–378 to +187
– 1551 nm channel	ps/nm	0 to +2012	–302 to +312	0 to +1778	–277 to +286
– 1571 nm channel	ps/nm	0 to +2150	–193 to +432	0 to +1900	–177 to +396
Minimum optical return loss at MPI-S_M	dB	24	24	24	24
Maximum discrete reflectance between MPI-S_M and MPI-R_M	dB	−27	−27	−27	−27
Maximum differential group delay	ps	120	120	120	120

Table 8-3 – Physical layer parameters and values for multichannel interfaces for 4-channel NRZ 1.25G and NRZ 2.5G bidirectional long-haul black box applications

Parameter	Units	B-C4L1-0D2	B-C4L1-0D3	B-C4L1-1D2	B-C4L1-1D3
Interface at point MPI-R_M					
Maximum mean channel input power	dBm	−7	−7	−7	−7
Minimum mean channel input power	dBm	−25.5	−25.5	−22.5	−23.5
Maximum mean total input power	dBm	−4	−4	−4	−4
Maximum optical path penalty	dB	1.5	1.5	2.5	1.5
Minimum equivalent sensitivity	dBm	−27	−27	−25	−25
Maximum reflectance of optical network element	dB	−27	−27	−27	−27

[a] A system with ±7 nm maximum central wavelength deviation which is compliant with all other ITU-T G.695 parameter values of the relevant application code is transversely compatible for any applications covered by that code, except that it does not provide transverse compatibility with a ±6.5 nm system without joint engineering.

[b] The transmit power levels for these 2 + 2 channel bidirectional applications are higher than for other applications in this Recommendation, so that a target distance of 80 km is achievable for NRZ 2.5G.

Table 8-4 – Physical layer parameters and values for multichannel interfaces for 8-channel NRZ 2.5G black box applications

Parameter	Units	C8S1-1D2	B-C8S1-1D2	C8L1-1D2
General information				
Maximum number of channels	–	8	4 + 4	8
Bit rate/line coding of optical tributary signals	–	NRZ 2.5G	NRZ 2.5G	NRZ 2.5G
Maximum bit error ratio	–	10^{-12}	10^{-12}	10^{-12}
Fibre type	–	G.652	G.652	G.652
Interface at point MPI-S_M				
Maximum mean channel output power	dBm	+4	+4	+4
Minimum mean channel output power	dBm	–3.5	–3.5	–3.5
Maximum mean total output power	dBm	+13	+10	+13
Central wavelength	nm	1471 + 20 m, m = 0 to 7	1471 + 20 m, m = 0 to 7	1471 + 20 m, m = 0 to 7
Channel spacing	nm	20	20	20
Maximum central wavelength deviation (Note)	nm	±6.5	±6.5	±6.5
Minimum channel extinction ratio	dB	8.2	8.2	8.2
Eye mask	–	STM-16 per G.957	STM-16 per G.957	STM-16 per G.957

Table 8-4 – Physical layer parameters and values for multichannel interfaces for 8-channel NRZ 2.5G black box applications

Parameter	Units	C8S1-1D2	B-C8S1-1D2	C8L1-1D2
Optical path (single span) from point MPI-S_M to MPI-R_M				
Maximum attenuation	dB	9	9	18
Minimum attenuation	dB	3	3	12
Chromatic dispersion range				
– 1471 nm channel	ps/nm	0 to +481	0 to +481	0 to +962
– 1491 nm channel	ps/nm	0 to +526	0 to +526	0 to +1051
– 1511 nm channel	ps/nm	0 to +571	0 to +571	0 to +1143
– 1531 nm channel	ps/nm	0 to +616	0 to +616	0 to +1233
– 1551 nm channel	ps/nm	0 to +662	0 to +662	0 to +1325
– 1571 nm channel	ps/nm	0 to +708	0 to +708	0 to +1416
– 1591 nm channel	ps/nm	0 to +754	0 to +754	0 to +1507
– 1611 nm channel	ps/nm	0 to +800	0 to +800	0 to +1600
Minimum optical return loss at MPI-S_M	dB	24	24	24
Maximum discrete reflectance between MPI-S_M and MPI-R_M	dB	–27	–27	–27
Maximum differential group delay	ps	120	120	120
Interface at point MPI-R_M				
Maximum mean channel input power	dBm	+1	+1	–8
Minimum mean channel input power	dBm	–12.5	–12.5	–21.5
Maximum mean total input power	dBm	+10	+7	+1
Maximum optical path penalty	dB	1.5	1.5	2.5
Minimum equivalent sensitivity	dBm	–14	–14	–24
Maximum reflectance of optical network element	dB	–27	–27	–27
NOTE – A system with ±7 nm maximum central wavelength deviation which is compliant with all other ITU-T G.695 parameter values of the relevant application code is transversely compatible for any applications covered by that code, except that it does not provide transverse compatibility with a ±6.5 nm system without joint engineering.				

Table 8-5 – Physical layer parameters and values for multichannel interfaces for 8-channel NRZ 1.25G and NRZ 2.5G bidirectional long-haul black box applications

Parameter	Units	B-C8L1-0D2	B-C8L1-0D3	B-C8L1-1D2	B-C8L1-1D3
General information					
Maximum number of channels	–	4 + 4	4 + 4	4 + 4	4 + 4
Bit rate/line coding of optical tributary signals	–	NRZ 1.25G	NRZ 1.25G	NRZ 2.5G	NRZ 2.5G
Maximum bit error ratio	–	10^{-12}	10^{-12}	10^{-12}	10^{-12}
Fibre type	–	G.652	G.653	G.652	G.653
Interface at point MPI-S_M					
Maximum mean channel output power	dBm	+4	+4	+4	+4
Minimum mean channel output power	dBm	−3.5	−3.5	−3.5	−3.5
Maximum mean total output power	dBm	+10	+10	+10	+10
Central wavelength	nm	1471 + 20 m, m = 0 to 7	1471 + 20 m, m = 0 to 7	1471 + 20 m, m = 0 to 7	1471 + 20 m, m = 0 to 7
Channel spacing	nm	20	20	20	20
Maximum central wavelength deviation (Note)	nm	±6.5	±6.5	±6.5	±6.5
Minimum channel extinction ratio	dB	8.2	8.2	8.2	8.2
Eye mask	–	STM-4 per G.957	STM-4 per G.957	STM-16 per G.957	STM-16 per G.957
Optical path (single span) from point MPI-S_M to MPI-R_M					
Maximum attenuation	dB	21	21	18	19
Minimum attenuation	dB	12	12	12	12
Chromatic dispersion range					
– 1471 nm channel	ps/nm	0 to +1118	–770 to 0	0 to +962	–690 to 0
– 1491 nm channel	ps/nm	0 to +1222	–618 to 0	0 to +1051	–554 to 0
– 1511 nm channel	ps/nm	0 to +1328	–467 to +73	0 to +1143	–418 to +65
– 1531 nm channel	ps/nm	0 to +1433	–315 to +156	0 to +1233	–283 to +140
– 1551 nm channel	ps/nm	0 to +1540	–231 to +239	0 to + 1325	–207 to +214
– 1571 nm channel	ps/nm	0 to +1646	–148 to +331	0 to +1416	–133 to +296
– 1591 nm channel	ps/nm	0 to +1752	–64 to +482	0 to +1507	–58 to +432
– 1611 nm channel	ps/nm	0 to +1860	0 to +634	0 to +1600	0 to +568
Minimum optical return loss at MPI-S_M	dB	24	24	24	24
Maximum discrete reflectance between MPI-S_M and MPI-R_M	dB	−27	−27	−27	−27
Maximum differential group delay	ps	120	120	120	120

Table 8-5 – Physical layer parameters and values for multichannel interfaces for 8-channel NRZ 1.25G and NRZ 2.5G bidirectional long-haul black box applications

Parameter	Units	B-C8L1-0D2	B-C8L1-0D3	B-C8L1-1D2	B-C8L1-1D3
Interface at point MPI-R_M					
Maximum mean channel input power	dBm	−8	−8	−8	−8
Minimum mean channel input power	dBm	−24.5	−24.5	−21.5	−22.5
Maximum mean total input power	dBm	−2	−2	−2	−2
Maximum optical path penalty	dB	1.5	1.5	2.5	1.5
Minimum equivalent sensitivity	dBm	−26	−26	−24	−24
Maximum reflectance of optical network element	dB	−27	−27	−27	−27
NOTE – A system with ±7 nm maximum central wavelength deviation which is compliant with all other ITU-T G.695 parameter values of the relevant application code is transversely compatible for any applications covered by that code, except that it does not provide transverse compatibility with a ±6.5 nm system without joint engineering.					

Table 8-6 – Physical layer parameters and values for multichannel interfaces for 12-channel NRZ 1.25G and NRZ 2.5G bidirectional long-haul black box applications

Parameter	Units	B-C12L1-0D2		B-C12L1-1D2	
Wavelength block	nm	1291-1351	1471-1611	1291-1351	1471-1611
General information					
Maximum number of channels	–	6 + 6		6 + 6	
Bit rate/line coding of optical tributary signals	–	NRZ 1.25G		NRZ 2.5G	
Maximum bit error ratio	–	10^{-12}		10^{-12}	
Fibre type	–	G.652		G.652	
Interface at point MPI-S_M					
Maximum mean channel output power	dBm	+3.5	+1.5	+3.5	+1.5
Minimum mean channel output power	dBm	−4	−6	−4	−6
Maximum mean total output power	dBm	+10.7		+10.7	
Central wavelength	nm	1291 + 20 m, m = 0 to 3	1471 + 20 m, m = 0 to 7	1291 + 20 m, m = 0 to 3	1471 + 20 m, m = 0 to 7
Channel spacing	nm	20		20	
Maximum central wavelength deviation (Note)	nm	±6.5		±6.5	

Table 8-6 – Physical layer parameters and values for multichannel interfaces for 12-channel NRZ 1.25G and NRZ 2.5G bidirectional long-haul black box applications

Parameter	Units	B-C12L1-0D2		B-C12L1-1D2	
Minimum channel extinction ratio	dB	8.2		8.2	
Eye mask	–	STM-4 per G.957		STM-16 per G.957	
Optical path (single span) from point MPI-S_M to MPI-R_M					
Maximum attenuation	dB	20	14.7	18	12.8
Minimum attenuation	dB	11	7	11	7
Chromatic dispersion range					
– 1291 nm channel	ps/nm	–208 to 0		–188 to 0	
– 1311 nm channel	ps/nm	–100 to +86		–91 to +78	
– 1331 nm channel	ps/nm	0 to +181		0 to +163	
– 1351 nm channel	ps/nm	0 to +271		0 to +245	
– 1471 nm channel	ps/nm		0 to +685		0 to +619
– 1491 nm channel	ps/nm		0 to +749		0 to +677
– 1511 nm channel	ps/nm		0 to +814		0 to +736
– 1531 nm channel	ps/nm		0 to +878		0 to +794
– 1551 nm channel	ps/nm		0 to +944		0 to +853
– 1571 nm channel	ps/nm		0 to +1009		0 to +911
– 1591 nm channel	ps/nm		0 to +1074		0 to +970
– 1611 nm channel	ps/nm		0 to +1140		0 to +1030
Minimum optical return loss at MPI-S_M	dB	24		24	
Maximum discrete reflectance between MPI-S_M and MPI-R_M	dB	−27		−27	
Maximum differential group delay	ps	120		120	
Interface at point MPI-R_M					
Maximum mean channel input power	dBm	−7.5	−5.5	−7.5	−5.5
Minimum mean channel input power	dBm	−24	−20.7	−22	−18.8
Maximum mean total input power	dBm	+2.3		+2.3	
Maximum optical path penalty	dB	1	1	1	2
Minimum equivalent sensitivity	dBm	−25	−21.7	−23	−20.8
Maximum reflectance of optical network element	dB	−27		−27	
NOTE – A system with ±7 nm maximum central wavelength deviation which is compliant with all other ITU-T G.695 parameter values of the relevant application code is transversely compatible for any applications covered by that code, except that it does not provide transverse compatibility with a ±6.5 nm system without joint engineering.					

Table 8-7 – Physical layer parameters and values for multichannel interfaces for 16-channel NRZ 2.5G black box application C16S1-1D2

Parameter	Units	C16S1-1D2
Wavelength block	nm	ffs
General information		
Maximum number of channels	–	16
Bit rate/line coding of optical tributary signals	–	NRZ 2.5G
Maximum bit error ratio	–	10^{-12}
Fibre type	–	G.652.C or G.652.D
Interface at point MPI-S_M		
Maximum mean channel output power	dBm	ffs
Minimum mean channel output power	dBm	ffs
Maximum mean total output power	dBm	ffs
Central wavelength	nm	ffs
Channel spacing	nm	20
Maximum central wavelength deviation (Note)	nm	±6.5
Minimum channel extinction ratio	dB	8.2
Eye mask	–	STM-16 per G.957
Optical path (single span) from point MPI-S_M to MPI-R_M		
Maximum attenuation	dB	ffs
Minimum attenuation	dB	ffs
Chromatic dispersion range	ps/nm	ffs
Minimum optical return loss at MPI-S_M	dB	ffs
Maximum discrete reflectance between MPI-S_M and MPI-R_M	dB	ffs
Maximum differential group delay	ps	120
Interface at point MPI-R_M		
Maximum mean channel input power	dBm	ffs
Minimum mean channel input power	dBm	ffs
Maximum mean total input power	dBm	ffs
Maximum optical path penalty	dB	ffs
Minimum equivalent sensitivity	dBm	ffs
Maximum reflectance of optical network element	dB	ffs
NOTE – A system with ±7 nm maximum central wavelength deviation which is compliant with all other ITU-T G.695 parameter values of the relevant application code is transversely compatible for any applications covered by that code, except that it does not provide transverse compatibility with a ±6.5 nm system without joint engineering.		

Table 8-8 – Physical layer parameters and values for multichannel interfaces for 16-channel NRZ 2.5G black box application C16L1-1D2

Parameter	Units	C16L1-1D2
Wavelength block	nm	ffs
General information		
Maximum number of channels	–	16
Bit rate/line coding of optical tributary signals	–	NRZ 2.5G
Maximum bit error ratio	–	10^{-12}
Fibre type	–	G.652.C or G.652.D
Interface at point MPI-S_M		
Maximum mean channel output power	dBm	ffs
Minimum mean channel output power	dBm	ffs
Maximum mean total output power	dBm	ffs
Central wavelength	nm	ffs
Channel spacing	nm	20
Maximum central wavelength deviation (Note)	nm	±6.5
Minimum channel extinction ratio	dB	8.2
Eye mask	–	STM-16 per G.957
Optical path (single span) from point MPI-S_M to MPI-R_M		
Maximum attenuation	dB	ffs
Minimum attenuation	dB	ffs
Chromatic dispersion range	ps/nm	ffs
Minimum optical return loss at MPI-S_M	dB	ffs
Maximum discrete reflectance between MPI-S_M and MPI-R_M	dB	ffs
Maximum differential group delay	ps	120
Interface at point MPI-R_M		
Maximum mean channel input power	dBm	ffs
Minimum mean channel input power	dBm	ffs
Maximum mean total input power	dBm	ffs
Maximum optical path penalty	dB	ffs
Minimum equivalent sensitivity	dBm	ffs
Maximum reflectance of optical network element	dB	ffs
NOTE – A system with ±7 nm maximum central wavelength deviation which is compliant with all other ITU-T G.695 parameter values of the relevant application code is transversely compatible for any applications covered by that code, except that it does not provide transverse compatibility with a ±6.5 nm system without joint engineering.		

Table 8-9 – Physical layer parameters and values for multichannel interfaces for 16-channel NRZ 2.5G black box application B-C16S1-1D2

Parameter	Units	B-C16S1-1D2
Wavelength block	nm	ffs
General information		
Maximum number of channels	–	8 + 8
Bit rate/line coding of optical tributary signals	–	NRZ 2.5G
Maximum bit error ratio	–	10^{-12}
Fibre type	–	G.652.C or G.652.D
Interface at point MPI-S_M		
Maximum mean channel output power	dBm	ffs
Minimum mean channel output power	dBm	ffs
Maximum mean total output power	dBm	ffs
Central wavelength	nm	ffs
Channel spacing	nm	20
Maximum central wavelength deviation (Note)	nm	±6.5
Minimum channel extinction ratio	dB	8.2
Eye mask	–	STM-16 per G.957
Optical path (single span) from point MPI-S_M to MPI-R_M		
Maximum attenuation	dB	ffs
Minimum attenuation	dB	ffs
Chromatic dispersion range	ps/nm	ffs
Minimum optical return loss at MPI-S_M	dB	ffs
Maximum discrete reflectance between MPI-S_M and MPI-R_M	dB	ffs
Maximum differential group delay	ps	120
Interface at point MPI-R_M		
Maximum mean channel input power	dBm	ffs
Minimum mean channel input power	dBm	ffs
Maximum mean total input power	dBm	ffs
Maximum optical path penalty	dB	ffs
Minimum equivalent sensitivity	dBm	ffs
Maximum reflectance of optical network element	dB	ffs
NOTE – A system with ±7 nm maximum central wavelength deviation which is compliant with all other ITU-T G.695 parameter values of the relevant application code is transversely compatible for any applications covered by that code, except that it does not provide transverse compatibility with a ±6.5 nm system without joint engineering.		

Table 8-10 – Physical layer parameters and values for multichannel interfaces for 16-channel NRZ 2.5G black box application B-C16L1-1D2

Parameter	Units	B-C16L1-1D2
Wavelength block	nm	ffs
General information		
Maximum number of channels	–	8 + 8
Bit rate/line coding of optical tributary signals	–	NRZ 2.5G
Maximum bit error ratio	–	10^{-12}
Fibre type	–	G.652.C or G.652.D
Interface at point MPI-S_M		
Maximum mean channel output power	dBm	ffs
Minimum mean channel output power	dBm	ffs
Maximum mean total output power	dBm	ffs
Central wavelength	nm	ffs
Channel spacing	nm	20
Maximum central wavelength deviation (Note)	nm	±6.5
Minimum channel extinction ratio	dB	8.2
Eye mask	–	STM-16 per G.957
Optical path (single span) from point MPI-S_M to MPI-R_M		
Maximum attenuation	dB	ffs
Minimum attenuation	dB	ffs
Chromatic dispersion range	ps/nm	ffs
Minimum optical return loss at MPI-S_M	dB	ffs
Maximum discrete reflectance between MPI-S_M and MPI-R_M	dB	ffs
Maximum differential group delay	ps	120
Interface at point MPI-R_M		
Maximum mean channel input power	dBm	ffs
Minimum mean channel input power	dBm	ffs
Maximum mean total input power	dBm	ffs
Maximum optical path penalty	dB	ffs
Minimum equivalent sensitivity	dBm	ffs
Maximum reflectance of optical network element	dB	ffs
NOTE – A system with ±7 nm maximum central wavelength deviation which is compliant with all other ITU-T G.695 parameter values of the relevant application code is transversely compatible for any applications covered by that code, except that it does not provide transverse compatibility with a ±6.5 nm system without joint engineering.		

Table 8-11 – Physical layer parameters and values for multichannel systems with single-channel interfaces for 4-channel NRZ 2.5G short-haul black link applications

Parameter	Units	S-C4S1-1D2	S-C4S1-1D3	S-C4S1-1D5
General information				
Maximum number of channels	–	4		
Bit rate/line coding of optical tributary signals	–	NRZ 2.5G		
Maximum bit error ratio	–	10^{-12}		
Fibre type	–	G.652	G.653	G.655
Interface at point S_S				
Maximum mean channel output power	dBm	+5		
Minimum mean channel output power	dBm	0		
Central wavelength	nm	1511 + 20 m, m = 0 to 3		
Channel spacing	nm	20		
Maximum central wavelength deviation (Note)	nm	±6.5		
Minimum channel extinction ratio	dB	8.2		
Eye mask	–	STM-16 per G.957		
Optical path from point S_S to R_S				
Maximum channel insertion loss	dB	16.5		
Minimum channel insertion loss	dB	5		
Chromatic dispersion range				
– 1511 nm channel	ps/nm	0 to +807	–350 to +55	0 to +446
– 1531 nm channel	ps/nm	0 to +872	–236 to +117	0 to +513
– 1551 nm channel	ps/nm	0 to +936	–173 to +179	0 to +581
– 1571 nm channel	ps/nm	0 to +1000	–111 to +248	0 to +650
Minimum optical return loss at S_S	dB	24		
Maximum discrete reflectance between S_S and R_S	dB	–27		
Maximum differential group delay	ps	120		
Maximum inter-channel crosstalk	dB	–20		
Maximum interferometric crosstalk	dB	–45		
Interface at point R_S				
Maximum mean channel input power	dBm	0		
Minimum receiver sensitivity	dBm	–18		
Maximum optical path penalty	dB	1.5		
Maximum reflectance of receiver	dB	–27		
NOTE – A system with ±7 nm maximum central wavelength deviation which is compliant with all other ITU-T G.695 parameter values of the relevant application code is transversely compatible for any applications covered by that code, except that it does not provide transverse compatibility with a ±6.5 nm system without joint engineering.				

Table 8-12 – Physical layer parameters and values for multichannel systems with single-channel interfaces for 4-channel NRZ 2.5G long-haul black link applications

Parameter	Units	S-C4L1-1D2	S-C4L1-1D3	S-C4L1-1D5
General information				
Maximum number of channels	–	4		
Bit rate/line coding of optical tributary signals	–	NRZ 2.5G		
Maximum bit error ratio	–	10^{-12}		
Fibre type	–	G.652	G.653	G.655
Interface at point S_S				
Maximum mean channel output power	dBm	+5		
Minimum mean channel output power	dBm	0		
Central wavelength	nm	1511 + 20 m, m = 0 to 3		
Channel spacing	nm	20		
Maximum central wavelength deviation (Note)	nm	±6.5		
Minimum channel extinction ratio	dB	8.2		
Eye mask	–	STM-16 per G.957		
Optical path from point S_S to R_S				
Maximum channel insertion loss	dB	25.5	26.5	26
Minimum channel insertion loss	dB	14	14	14
Chromatic dispersion range				
– 1511 nm channel	ps/nm	0 to +1332	–600 to +94	0 to +756
– 1531 nm channel	ps/nm	0 to +1437	–405 to +200	0 to +869
– 1551 nm channel	ps/nm	0 to +1544	–297 to +307	0 to +983
– 1571 nm channel	ps/nm	0 to +1650	–190 to +425	0 to +1100
Minimum optical return loss at S_S	dB	24		
Maximum discrete reflectance between S_S and R_S	dB	–27		
Maximum differential group delay	ps	120		
Maximum inter-channel crosstalk	dB	–20		
Maximum interferometric crosstalk	dB	–45		
Interface at point R_S				
Maximum mean channel input power	dBm	–9		
Minimum receiver sensitivity	dBm	–28		
Maximum optical path penalty	dB	2.5	1.5	2
Maximum reflectance of receiver	dB	–27		
NOTE – A system with ±7 nm maximum central wavelength deviation which is compliant with all other ITU-T G.695 parameter values of the relevant application code is transversely compatible for any applications covered by that code, except that it does not provide transverse compatibility with a ±6.5 nm system without joint engineering.				

Table 8-13 – Physical layer parameters and values for multichannel systems with single-channel interfaces for 8-channel NRZ 2.5G short-haul black link applications

Parameter	Units	S-C8S1-1D2	S-C8S1-1D3	S-C8S1-1D5
General information				
Maximum number of channels	–	8	8	8[b)]
Bit rate/line coding of optical tributary signals	–	NRZ 2.5G		
Maximum bit error ratio	–	10^{-12}		
Fibre type	–	G.652	G.653	G.655
Interface at point S_S				
Maximum mean channel output power	dBm	+5		
Minimum mean channel output power	dBm	0		
Central wavelength	nm	1471 + 20 m, m = 0 to 7		
Channel spacing	nm	20		
Maximum central wavelength deviation[a)]	nm	±6.5		
Minimum channel extinction ratio	dB	8.2		
Eye mask	–	STM-16 per G.957		
Optical path from point S_S to R_S				
Maximum channel insertion loss	dB	16.5		
Minimum channel insertion loss	dB	5		
Chromatic dispersion range				
– 1471 nm channel	ps/nm	0 to +601	–500 to 0	–174 to +279
– 1491 nm channel	ps/nm	0 to +657	–402 to 0	–85 to +337
– 1511 nm channel	ps/nm	0 to +714	–303 to +47	0 to +396
– 1531 nm channel	ps/nm	0 to +771	–205 to +101	0 to +456
– 1551 nm channel	ps/nm	0 to +828	–150 to +155	0 to +516
– 1571 nm channel	ps/nm	0 to +885	–96 to +215	0 to +577
– 1591 nm channel	ps/nm	0 to +942	–42 to +313	0 to +639
– 1611 nm channel	ps/nm	0 to +1000	0 to +411	0 to +700
Minimum optical return loss at S_S	dB	24		
Maximum discrete reflectance between S_S and R_S	dB	–27		
Maximum differential group delay	ps	120		
Maximum inter-channel crosstalk	dB	–20		
Maximum interferometric crosstalk	dB	–45		

Table 8-13 – Physical layer parameters and values for multichannel systems with single-channel interfaces for 8-channel NRZ 2.5G short-haul black link applications

Interface at point R_S		
Maximum mean channel input power	dBm	0
Minimum receiver sensitivity	dBm	–18
Maximum optical path penalty	dB	1.5
Maximum reflectance of receiver	dB	–27

a) A system with ±7 nm maximum central wavelength deviation which is compliant with all other ITU-T G.695 parameter values of the relevant application code is transversely compatible for any applications covered by that code, except that it does not provide transverse compatibility with a ±6.5 nm system without joint engineering.

b) The 1471 nm channel may not be usable with older ITU-T G.655 fibre that has a maximum cable cut-off wavelength specified as 1480 nm.

Table 8-14 – Physical layer parameters and values for multichannel systems with single-channel interfaces for 8-channel NRZ 2.5G long-haul black link applications

Parameter	Units	S-C8L1-1D2	S-C8L1-1D3	S-C8L1-1D5
General information				
Maximum number of channels	–	8	8	8[b)]
Bit rate/line coding of optical tributary signals	–	NRZ 2.5G		
Maximum bit error ratio	–	10^{-12}		
Fibre type	–	G.652	G.653	G.655
Interface at point S_S				
Maximum mean channel output power	dBm	+5		
Minimum mean channel output power	dBm	0		
Central wavelength	nm	1471 + 20 m, m = 0 to 7		
Channel spacing	nm	20		
Maximum central wavelength deviation[a)]	nm	±6.5		
Minimum channel extinction ratio	dB	8.2		
Eye mask	–	STM-16 per G.957		
Optical path from point S_S to R_S				
Maximum channel insertion loss	dB	25.5	26	26
Minimum channel insertion loss	dB	14		
Chromatic dispersion range				
– 1471 nm channel	ps/nm	0 to +1022	–850 to 0	–286 to +458
– 1491 nm channel	ps/nm	0 to +1118	–683 to 0	–139 to +554
– 1511 nm channel	ps/nm	0 to +1214	–516 to +81	0 to +651
– 1531 nm channel	ps/nm	0 to +1310	–348 to +172	0 to +749
– 1551 nm channel	ps/nm	0 to +1407	–255 to +264	0 to +847
– 1571 nm channel	ps/nm	0 to +1504	–163 to +365	0 to +948
– 1591 nm channel	ps/nm	0 to +1602	–71 to +532	0 to +1049

Table 8-14 – Physical layer parameters and values for multichannel systems with single-channel interfaces for 8-channel NRZ 2.5G long-haul black link applications

Parameter	Units	S-C8L1-1D2	S-C8L1-1D3	S-C8L1-1D5
– 1611 nm channel	ps/nm	0 to +1700	0 to +699	0 to +1150
Minimum optical return loss at S_S	dB	24		
Maximum discrete reflectance between S_S and R_S	dB	–27		
Maximum differential group delay	ps	120		
Maximum inter-channel crosstalk	dB	–20		
Maximum interferometric crosstalk	dB	–45		
Interface at point R_S				
Maximum mean channel input power	dBm	–9		
Minimum receiver sensitivity	dBm	–28		
Maximum optical path penalty	dB	2.5	2	2
Maximum reflectance of receiver	dB	–27		

a) A system with ±7 nm maximum central wavelength deviation which is compliant with all other ITU-T G.695 parameter values of the relevant application code is transversely compatible for any applications covered by that code, except that it does not provide transverse compatibility with a ±6.5 nm system without joint engineering.

b) The 1471 nm channel may not be usable with older ITU-T G.655 fibre that has a maximum cable cut-off wavelength specified as 1480 nm.

Table 8-15 – Physical layer parameters and values for multichannel interfaces for optical tributary signal class NRZ 10G, 4-channel black box applications

Parameter	Units	C4S1-2D1
General information		
Maximum number of channels	–	4
Bit rate/line coding of optical tributary signals	–	NRZ 10G
Maximum bit error ratio	–	10^{-12}
Fibre type	–	G.652
Interface at point MPI-S_M		
Maximum mean channel output power	dBm	+2.3
Minimum mean channel output power	dBm	−2.3
Maximum mean total output power	dBm	+8.3
Central wavelength	nm	1271 + 20 m, m = 0 to 3
Channel spacing	nm	20
Maximum central wavelength deviation (Note)	nm	±6.5
Minimum channel extinction ratio	dB	4.5
Eye mask	–	NRZ 10G ratio small per G.959.1

Table 8-15 – Physical layer parameters and values for multichannel interfaces for optical tributary signal class NRZ 10G, 4-channel black box applications

Parameter	Units	C4S1-2D1
Optical path (single span) from point MPI-S_M to MPI-R_M		
Maximum attenuation	dB	6.7
Minimum attenuation	dB	0
Chromatic dispersion range		
– 1271 nm channel	ps/nm	–59.5 to 0
– 1291 nm channel	ps/nm	–39 to 0
– 1311 nm channel	ps/nm	–19 to +16
– 1331 nm channel	ps/nm	0 to +33.5
Minimum optical return loss at MPI-S_M	dB	20
Maximum discrete reflectance between MPI-S_M and MPI-R_M	dB	−26
Maximum differential group delay	ps	10
Interface at point MPI-R_M		
Maximum mean channel input power	dBm	+2.3
Minimum mean channel input power	dBm	–9
Maximum mean total input power	dBm	+8.3
Maximum optical path penalty	dB	1.5
Minimum equivalent sensitivity	dBm	–10.5
Maximum reflectance of optical network element	dB	−26
NOTE – A system with ±7 nm maximum central wavelength deviation which is compliant with all other ITU-T G.695 parameter values of the relevant application code is transversely compatible for any applications covered by that code, except that it does not provide transverse compatibility with a ±6.5 nm system without joint engineering.		

Table 8-16 – Physical layer parameters and values for multichannel interfaces for 8-channel NRZ OTU2 bidirectional long-haul black box applications

Parameter	Units	B-C8L1-2D2F	B-C8L1-2D3F
General information			
Maximum number of channels	–	4 + 4	
Bit rate/line coding of optical tributary signals	–	NRZ OTU2 FEC enabled	
Maximum bit error ratio	–	10^{-12}	
Fibre type	–	G.652	G.653
Interface at point MPI-S_M			
Maximum mean channel output power	dBm	+5	
Minimum mean channel output power	dBm	−2	
Maximum mean total output power	dBm	+11	

Table 8-16 – Physical layer parameters and values for multichannel interfaces for 8-channel NRZ OTU2 bidirectional long-haul black box applications

Parameter	Units	B-C8L1-2D2F	B-C8L1-2D3F
Central wavelength	nm	1471 + 20 m, m = 0 to 7	
Channel spacing	nm	20	
Maximum central wavelength deviation (Note 1)	nm	±6.5	
Minimum channel extinction ratio	dB	8.2	
Eye mask	–	NRZ 10G Ratio large per G.959.1	
Optical path (single span) from point MPI-S_M to MPI-R_M			
Maximum attenuation	dB	18	19
Minimum attenuation	dB	12	
Chromatic dispersion range			
– 1471 nm channel	ps/nm	0 to +962	–500 to 0
– 1491 nm channel	ps/nm	0 to +1051	–402 to 0
– 1511 nm channel	ps/nm	0 to +1143	–303 to +47
– 1531 nm channel	ps/nm	0 to +1233	–205 to +101
– 1551 nm channel	ps/nm	0 to +1325	–150 to +155
– 1571 nm channel	ps/nm	0 to +1416	–96 to +215
– 1591 nm channel	ps/nm	0 to +1507	–42 to +313
– 1611 nm channel	ps/nm	0 to +1600	0 to +411
Minimum optical return loss at MPI-S_M	dB	24	
Maximum discrete reflectance between MPI-S_M and MPI-R_M	dB	−27	
Maximum differential group delay	ps	30	
Interface at point MPI-R_M			
Maximum mean channel input power	dBm	−7	
Minimum mean channel input power	dBm	−20	–21
Maximum mean total input power	dBm	−1	
Maximum optical path penalty	dB	2.5	1.5
Minimum equivalent sensitivity	dBm	−22.5	
Maximum reflectance of optical network element	dB	−27	

NOTE 1 – A system with ±7 nm maximum central wavelength deviation which is compliant with all other ITU-T G.695 parameter values of the relevant application code is transversely compatible for any applications covered by that code, except that it does not provide transverse compatibility with a ±6.5 nm system without joint engineering.

NOTE 2 – The BER for these application codes is required to be met only after the error correction (if used) has been applied. The BER at the input of the FEC decoder can, therefore, be significantly higher than 10^{-12}.

Table 8-17 – Physical layer parameters and values for multichannel systems with single-channel interfaces for 4-channel NRZ 10G long-haul black link applications

Parameter	Units	S-C4L1-2D2	S-C4L1-2D3	S-C4L1-2D5
General information				
Maximum number of channels	–	4		
Bit rate/line coding of optical tributary signals	–	NRZ 10G		
Maximum bit error ratio	–	10^{-12}		
Fibre type	–	G.652	G.653	G.655
Interface at point S_S				
Maximum mean channel output power	dBm	+5		
Minimum mean channel output power	dBm	+1		
Central wavelength	nm	1511 + 20 m, m = 0 to 3		
Channel spacing	nm	20		
Maximum central wavelength deviation (Note)	nm	±6.5		
Minimum channel extinction ratio	dB	8.2		
Eye mask	–	NRZ 10G ratio large per G.959.1		
Optical path from point S_S to R_S				
Maximum channel insertion loss	dB	22.5	23.5	23
Minimum channel insertion loss	dB	12		
Chromatic dispersion range				
– 1511 nm channel	ps/nm	0 to +1130	–550 to +86	0 to +653
– 1531 nm channel	ps/nm	0 to +1219	–372 to +184	0 to +750
– 1551 nm channel	ps/nm	0 to +1310	–272 to +281	0 to +849
– 1571 nm channel	ps/nm	0 to +1400	–174 to +389	0 to +950
Minimum optical return loss at S_S	dB	24		
Maximum discrete reflectance between S_S and R_S	dB	–27		
Maximum differential group delay	ps	30		
Maximum inter-channel crosstalk	dB	–20		
Maximum interferometric crosstalk	dB	–45		
Interface at point R_S				
Maximum mean channel input power	dBm	–7		
Minimum receiver sensitivity	dBm	–24		
Maximum optical path penalty	dB	2.5	1.5	2
Maximum reflectance of receiver	dB	–27		
NOTE – A system with ±7 nm maximum central wavelength deviation which is compliant with all other ITU-T G.695 parameter values of the relevant application code is transversely compatible for any applications covered by that code, except that it does not provide transverse compatibility with a ±6.5 nm system without joint engineering.				

Table 8-18 – Physical layer parameters and values for multichannel systems with single-channel interfaces for 4-channel NRZ OTU2 long-haul black link applications

Parameter	Units	S-C4L1-2D2F	S-C4L1-2D3F	S-C4L1-2D5F
General information				
Maximum number of channels	–	4		
Bit rate/line coding of optical tributary signals	–	NRZ OTU2 FEC enabled		
Maximum bit error ratio	–	10^{-12}		
Fibre type	–	G.652	G.653	G.655
Interface at point S_S				
Maximum mean channel output power	dBm	+5		
Minimum mean channel output power	dBm	+1		
Central wavelength	nm	1511 + 20 m, m = 0 to 3		
Channel spacing	nm	20		
Maximum central wavelength deviation (Note 1)	nm	±6.5		
Minimum channel extinction ratio	dB	8.2		
Eye mask	–	NRZ 10G ratio large per G.959.1		
Optical path from point S_S to R_S				
Maximum channel insertion loss	dB	25.5	26.5	26
Minimum channel insertion loss	dB	12		
Chromatic dispersion range				
– 1511 nm channel	ps/nm	0 to +1332	–600 to +94	0 to +756
– 1531 nm channel	ps/nm	0 to +1437	–405 to +200	0 to +869
– 1551 nm channel	ps/nm	0 to +1544	–297 to +307	0 to +983
– 1571 nm channel	ps/nm	0 to +1650	–190 to +425	0 to +1100
Minimum optical return loss at S_S	dB	24		
Maximum discrete reflectance between S_S and R_S	dB	–27		
Maximum differential group delay	ps	30		
Maximum inter-channel crosstalk	dB	–20		
Maximum interferometric crosstalk	dB	–45		
Interface at point R_S				
Maximum mean channel input power	dBm	–7		
Minimum receiver sensitivity	dBm	–27		
Maximum optical path penalty	dB	2.5	1.5	2
Maximum reflectance of receiver	dB	–27		

NOTE 1 – A system with ±7 nm maximum central wavelength deviation which is compliant with all other ITU-T G.695 parameter values of the relevant application code is transversely compatible for any applications covered by that code, except that it does not provide transverse compatibility with a ±6.5 nm system without joint engineering.

NOTE 2 – The BER for these application codes is required to be met only after the error correction (if used) has been applied. The BER at the input of the FEC decoder can, therefore, be significantly higher than 10^{-12}.

Table 8-19 – Physical layer parameters and values for multichannel systems with single-channel interfaces for 8-channel NRZ 10G long-haul black link applications

Parameter	Units	S-C8L1-2D2	S-C8L1-2D3	S-C8L1-2D5
General information				
Maximum number of channels	–	8	8	8[b)]
Bit rate/line coding of optical tributary signals	–	NRZ 10G		
Maximum bit error ratio	–	10^{-12}		
Fibre type	–	G.652	G.653	G.655
Interface at point S_S				
Maximum mean channel output power	dBm	+5		
Minimum mean channel output power	dBm	+1		
Central wavelength	nm	1471 + 20 m, m = 0 to 7		
Channel spacing	nm	20		
Maximum central wavelength deviation[a)]	nm	±6.5		
Minimum channel extinction ratio	dB	8.2		
Eye mask	–	NRZ 10G ratio large per G.959.1		
Optical path from point S_S to R_S				
Maximum channel insertion loss	dB	22.5	23	23
Minimum channel insertion loss	dB	12		
Chromatic dispersion range				
– 1471 nm channel	ps/nm	0 to +842	–750 to 0	–262 to +418
– 1491 nm channel	ps/nm	0 to +920	–602 to 0	–127 to +506
– 1511 nm channel	ps/nm	0 to +1000	–455 to +71	0 to +595
– 1531 nm channel	ps/nm	0 to +1079	–307 to +152	0 to +684
– 1551 nm channel	ps/nm	0 to +1159	–225 to +233	0 to +774
– 1571 nm channel	ps/nm	0 to +1239	–144 to +322	0 to +866
– 1591 nm channel	ps/nm	0 to +1319	–63 to +470	0 to +958
– 1611 nm channel	ps/nm	0 to +1400	0 to +617	0 to +1050
Minimum optical return loss at S_S	dB	24		
Maximum discrete reflectance between S_S and R_S	dB	–27		
Maximum differential group delay	ps	30		
Maximum inter-channel crosstalk	dB	–20		
Maximum interferometric crosstalk	dB	–45		

Table 8-19 – Physical layer parameters and values for multichannel systems with single-channel interfaces for 8-channel NRZ 10G long-haul black link applications

Parameter	Units	S-C8L1-2D2	S-C8L1-2D3	S-C8L1-2D5
Interface at point R_S				
Maximum mean channel input power	dBm	–7		
Minimum receiver sensitivity	dBm	–24		
Maximum optical path penalty	dB	2.5	2	2
Maximum reflectance of receiver	dB	–27		

a) A system with ±7 nm maximum central wavelength deviation which is compliant with all other ITU-T G.695 parameter values of the relevant application code is transversely compatible for any applications covered by that code, except that it does not provide transverse compatibility with a ±6.5 nm system without joint engineering.

b) The 1471 nm channel may not be usable with older ITU-T G.655 fibre that has a maximum cable cut-off wavelength specified as 1480 nm.

Table 8-20 – Physical layer parameters and values for multichannel systems with single-channel interfaces for 8-channel NRZ OTU2 long-haul black link applications

Parameter	Units	S-C8L1-2D2F	S-C8L1-2D3F	S-C8L1-2D5F
General information				
Maximum number of channels	–	8	8	8[b]
Bit rate/line coding of optical tributary signals	–	NRZ OTU2 FEC enabled		
Maximum bit error ratio	–	10^{-12}		
Fibre type	–	G.652	G.653	G.655
Interface at point S_S				
Maximum mean channel output power	dBm	+5		
Minimum mean channel output power	dBm	+1		
Central wavelength	nm	1471 + 20 m, m = 0 to 7		
Channel spacing	nm	20		
Maximum central wavelength deviation[a]	nm	±6.5		
Minimum channel extinction ratio	dB	8.2		
Eye mask	–	NRZ 10G ratio large per G.959.1		
Optical path from point S_S to R_S				
Maximum channel insertion loss	dB	25.5	26	26
Minimum channel insertion loss	dB	12		
Chromatic dispersion range				
– 1471 nm channel	ps/nm	0 to +1022	–850 to 0	–286 to +458
– 1491 nm channel	ps/nm	0 to +1118	–683 to 0	–139 to +554
– 1511 nm channel	ps/nm	0 to +1214	–516 to +81	0 to +651
– 1531 nm channel	ps/nm	0 to +1310	–348 to +172	0 to +749
– 1551 nm channel	ps/nm	0 to +1407	–255 to +264	0 to +847

Table 8-20 – Physical layer parameters and values for multichannel systems with single-channel interfaces for 8-channel NRZ OTU2 long-haul black link applications

Parameter	Units	S-C8L1-2D2F	S-C8L1-2D3F	S-C8L1-2D5F
– 1571 nm channel	ps/nm	0 to +1504	–163 to +365	0 to +948
– 1591 nm channel	ps/nm	0 to +1602	–71 to +532	0 to +1049
– 1611 nm channel	ps/nm	0 to +1700	0 to +699	0 to +1150
Minimum optical return loss at S_S	dB		24	
Maximum discrete reflectance between S_S and R_S	dB		–27	
Maximum differential group delay	ps		30	
Maximum inter-channel crosstalk	dB		–20	
Maximum interferometric crosstalk	dB		–45	
Interface at point R_S				
Maximum mean channel input power	dBm		–7	
Minimum receiver sensitivity	dBm		–27	
Maximum optical path penalty	dB	2.5	2	2
Maximum reflectance of receiver	dB		–27	

[a] A system with ±7 nm maximum central wavelength deviation which is compliant with all other ITU-T G.695 parameter values of the relevant application code is transversely compatible for any applications covered by that code, except that it does not provide transverse compatibility with a ±6.5 nm system without joint engineering.

[b] The 1471 nm channel may not be usable with older ITU-T G.655 fibre that has a maximum cable cut-off wavelength specified as 1480 nm.

NOTE – The BER for these application codes is required to be met only after the error correction (if used) has been applied. The BER at the input of the FEC decoder can, therefore, be significantly higher than 10^{-12}.

9 Optical safety considerations

See [ITU-T G.664], [IEC 60825-1] and [IEC 60825-2] for optical safety considerations.

NOTE – Accessible emission limits for wavelengths above and below 1400 nm differ. Therefore, appropriate consideration must be given to how wavelengths in each of these regions contribute to the hazard level classification for CWDM applications.

Appendix I

Wavelength dependence of attenuation and chromatic dispersion

(This appendix does not form an integral part of this Recommendation)

I.1 Attenuation

The attenuation coefficient of an installed optical fibre cable is wavelength dependent, the value at a particular wavelength depending on the characteristics of the uncabled fibre together with additional losses caused by connectors, splicing and bending.

Table I.1 contains the assumed minimum and maximum attenuation coefficient values for each CWDM wavelength. They are also depicted graphically in Figures I.1 and I.2. These values were obtained by combining measurements of the attenuation coefficient of underground and buried optical fibre cables at 1550 nm and 1625 nm with full spectrum measurements of uncabled fibres and with the limits specified in [ITU-T G.652].

Table I.1 – Assumed attenuation coefficient values

Nominal central wavelength (nm)	ITU-T G.652.A and ITU-T G.652.B cable		ITU-T G.652.C and ITU-T G.652.D cable	
	Minimum attenuation coefficient (dB/km)	Maximum attenuation coefficient (dB/km)	Minimum attenuation coefficient (dB/km)	Maximum attenuation coefficient (dB/km)
1271	0.392	0.473	0.385	0.470
1291	0.370	0.447	0.365	0.441
1311	0.348	0.423	0.352	0.423
1331	0.331	0.425	0.340	0.411
1351	0.320	0.476	0.329	0.399
1371			0.316	0.386
1391			0.301	0.372
1411			0.285	0.357
1431	0.263	0.438	0.269	0.341
1451	0.250	0.368	0.254	0.326
1471	0.238	0.327	0.240	0.312
1491	0.229	0.303	0.229	0.300
1511	0.221	0.290	0.220	0.290
1531	0.215	0.283	0.213	0.283
1551	0.211	0.278	0.209	0.277
1571	0.208	0.276	0.208	0.273
1591	0.208	0.278	0.208	0.275
1611	0.208	0.289	0.212	0.283
NOTE – These coefficient values include an allowance for maximum central wavelength deviation.				

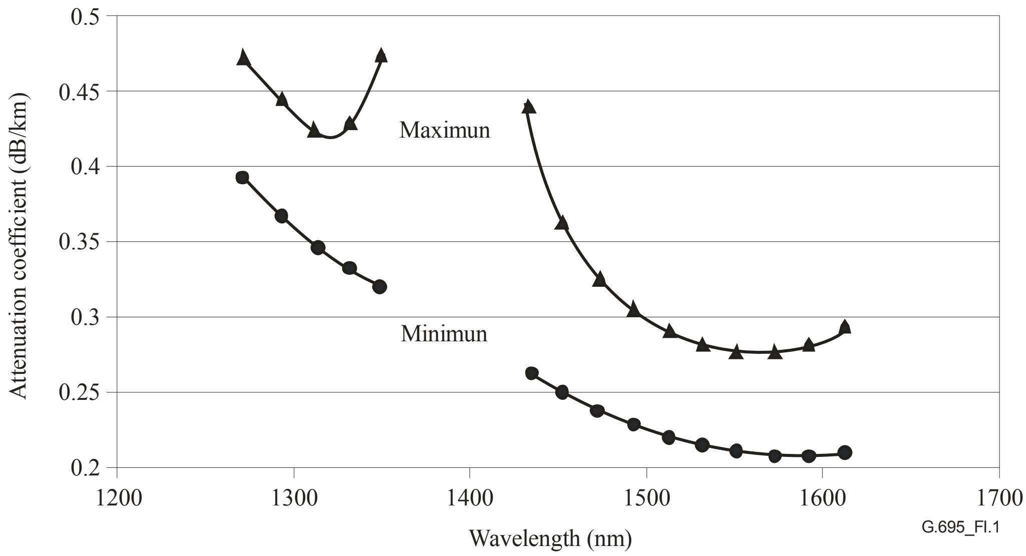

Figure I.1 – Assumed attenuation coefficient values for ITU-T G.652.A and ITU-T G.652.B cable

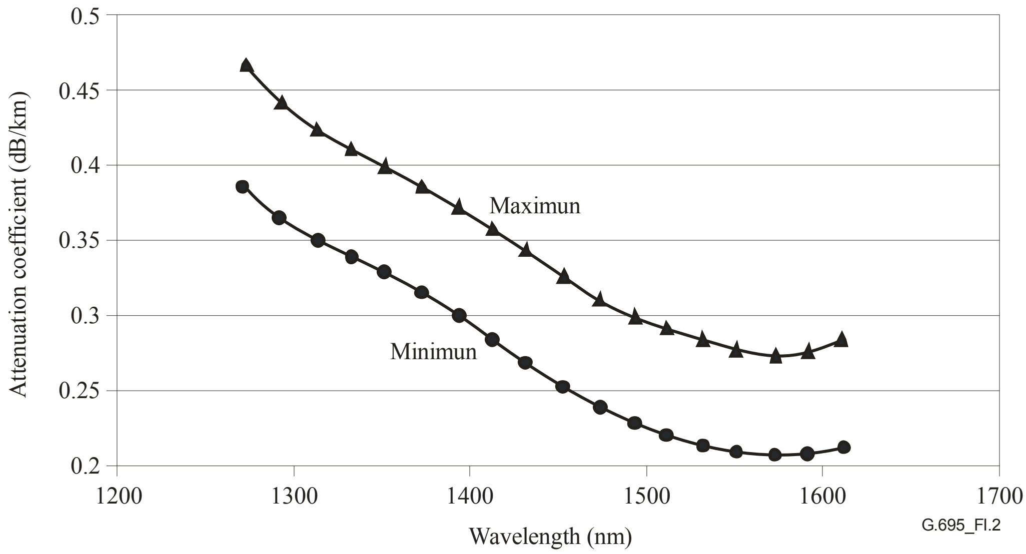

Figure I.2 – Assumed attenuation coefficient values for ITU-T G.652.C and ITU-T G.652.D cable

These attenuation coefficient values are based on the spectral results of a limited number of fibres, together with an assumption of 0.275 dB/km at 1550 nm for the maximum attenuation coefficients and 0.210 dB/km at 1550 nm for the minimum attenuation coefficients. Actual installed cable attenuation is statistical in nature and these values should not be taken as specification limits on individual fibres, cable sections or splices. In actual installed optical fibre cables, the attenuation coefficient values will differ from those shown in Table I.1 and Figure I.1 depending on factors such as connector loss, splicing loss, bending loss or loss due to optical monitoring.

I.2 Chromatic dispersion

As the chromatic dispersion coefficient is wavelength dependent, Table I.2 contains the assumed maximum chromatic dispersion coefficient values at the central wavelength (plus the maximum allowed central wavelength deviation) for each of the channels used in this Recommendation. The values of chromatic dispersion for ITU-T G.652 fibres for the 1391 nm channel and above have been calculated using [b-ITU-T G-Sup.39] equations 10-7a and 10-7b, with 1 sigma. For the

1371 nm channel and below, the dispersion values are derived from the equations found in [ITU-T G.652]. The values for ITU-T G.655 fibres have been calculated using equations in Table I.5 of [ITU-T G.655] for the maximum dispersion coefficient with 1 sigma for ITU-T G.655.E fibre. The values for ITU-T G.653 fibres have been calculated using the equations for the chromatic dispersion bounding curves provided in Table 2 of [ITU-T G.653] for ITU-T G.653.B attributes.

Table I.2 – Assumed chromatic dispersion coefficient values for ITU-T G.652, ITU-T G.653 and ITU-T G.655 fibres

Channel wavelength (nm)	**Maximum dispersion coefficient (ps/nm/km)**					
	G.652 fibres		G.653 fibres		G.655 fibres	
	Negative	Positive	Negative	Positive	Negative	Positive
1291	–3.85	–	–	–	–	–
1311	–1.85	1.60	–	–	–	–
1331	–	3.34	–	–	–	–
1351	–	5.02	–	–	–	–
1371	–	6.62	–	–	–	–
1391	–	7.97	–	–	–	–
1411	–	9.14	–	–	–	–
1431	–	10.31	–	–	–	–
1451	–	11.49	–	–	–	–
1471	–	12.68	–8.64	–	–2.99	4.78
1491	–	13.86	–6.94	–	–1.45	5.79
1511	–	15.06	–5.24	0.82	–	6.80
1531	–	16.25	–3.54	1.75	–	7.82
1551	–	17.46	–2.59	2.68	–	8.85
1571	–	18.66	–1.66	3.71	–	9.90
1591	–	19.87	–0.72	5.41	–	10.96
1611	–	21.09	–	7.11	–	12.01

Appendix II

Optical path from point RP_S to RP_R

(This appendix does not form an integral part of this Recommendation)

Tables 8-11 to 8-14 and Tables 8-17 to 8-20 recommend physical layer parameter values for the optical path from point S_S to point R_S for black link applications. The optical path from point S_S to R_S includes the path from RP_S to RP_R and a number of other network elements (NEs). In the case of linear black link applications, the NEs include an OM, an OD and (optionally) one or more OADMs. For ring black link applications, the NEs include all of the OADMs that are traversed by the path from S_S to R_S being considered. The total insertion loss and the total chromatic dispersion of the CWDM NEs and the optical path from RP_S to RP_R must not exceed the values specified for the optical path from point S_S to R_S.

Apportionment of (wavelength dependent) insertion loss to the CWDM NEs and to the optical path from RP_S to RP_R will depend on the characteristics of the NEs and the optical path from RP_S to RP_R. The assumed maximum attenuation coefficient values in Appendix I can be used to evaluate an assumed maximum channel insertion loss of each channel for the optical path from RP_S to RP_R and therefore expected distances for high loss fibre. Similarly, for low loss fibres, the minimum attenuation coefficient values in Appendix I can be used. In some cases, the expected distance will be dispersion limited.

Tables II.1 and II.2 contain informative parameter values for the optical path from RP_S to RP_R for various CWDM NE insertion loss values.

Table II.1 – Parameters and values for optical path from RP_S to RP_R for application codes S-C8S1-1D2, -1D3 and -1D5

Parameter	Units	Total CWDM network element insertion loss				
		7.5 dB	**6.5 dB**	**5.5 dB**	**4.5 dB**	**3.5 dB**
Optical path from point RP_S to RP_R						
Maximum attenuation	dB	9	10	11	12	13
Minimum attenuation	dB	0	0	0	0.5	1.5
Maximum chromatic dispersion	ps/nm	1000	1000	1000	1000	1000
Maximum differential group delay	ps	120	120	120	120	120
Expected distance for high loss fibre[a)]	km	27	30	33	36	39
Expected distance for low loss fibre[a)]	km	38	42	46	50[b)]	55[b)]

a) In actual installed optical fibre cables, the expected distance may differ from the values shown depending on variations in factors such as connector loss, splicing loss, bending loss.

b) For application code S-C8S1-1D2 which uses ITU-T G.652 fibre, the expected distance is dispersion limited to approximately 47 km.

Table II.2 – Parameters and values for optical path from RP_S to RP_R for application codes S-C8L1-1D2, -1D3 and -1D5

Parameter	Units	Total CWDM network element insertion loss				
		7.5 dB	**6.5 dB**	**5.5 dB**	**4.5 dB**	**3.5 dB**
Optical path from point RP_S to RP_R						
Maximum attenuation	dB	18	19	20	21	22
Minimum attenuation	dB	6.5	7.5	8.5	9.5	10.5
Maximum chromatic dispersion	ps/nm	1600	1600	1600	1600	1600
Maximum differential group delay	ps	120	120	120	120	120
Expected distance for high loss fibre[a)]	km	55	58	61	64	67
Expected distance for low loss fibre[a)]	km	75	79[b)]	84[b)]	88[b)]	92[b)]

a) In actual installed optical fibre cables, the expected distance may differ from the values shown depending on variations in factors such as connector loss, splicing loss, bending loss.

b) For application code S-C8L1-1D2 which uses ITU-T G.652 fibre, the expected distance is dispersion limited to approximately 75 km.

Appendix III

Black links containing OADMs

(This appendix does not form an integral part of this Recommendation)

III.1 Number of OADMs in a black link

The number of OADMs that can be used in a linear black link or on a black link ring depends on OM, OADM, OD, fibre and connector losses. The total loss from S_S to R_S must exceed the minimum channel insertion loss and must not exceed the maximum channel insertion loss for the application code being used for the path from S_S to R_S. Therefore we have:

$$IL_{min} \leq IL_{total} \leq IL_{max}$$

where:

- IL_{min} minimum channel insertion loss for the application code
- IL_{max} maximum channel insertion loss for the application code

and:

$$IL_{total} = IL_{OM} + N_{OADM} IL_{OADM} + IL_{OD} + N_{con} IL_{con} + \alpha \cdot L$$

where:

- IL_{OM} OM insertion loss or OADM add loss at point S_S for the wavelength being used from S_S to R_S
- N_{OADM} number of express OADMs
- IL_{OADM} express OADM insertion loss for the wavelength being used from S_S to R_S
- IL_{OD} OD insertion loss or OADM drop loss at point R_S for the wavelength being used from S_S to R_S
- N_{con} number of connectors between S_S and R_S
- IL_{con} connector insertion loss
- α attenuation coefficient of the fibre, in dB/km, for the wavelength being used from S_S to R_S
- L total length of fibre between S_S and R_S

An express OADM is one through which the wavelength of interest passes without being added or dropped. The maximum number of express OADMs in a path between S_S and R_S is therefore given by:

$$N_{OADM} = \left\lfloor \frac{IL_{max} - IL_{OM} - IL_{OD} - N_{con} IL_{con} - \alpha \cdot L}{IL_{OADM}} \right\rfloor$$

The evaluation of the maximum number of OADMs must be done for each S_S to R_S path in the network so that the maximum number of OADMs is not exceeded for any S_S to R_S path. This is quite simple for networks where all of the paths share a common hub (see Figure III.1), but becomes more complicated as the path topology becomes more complex (see Figure III.2).

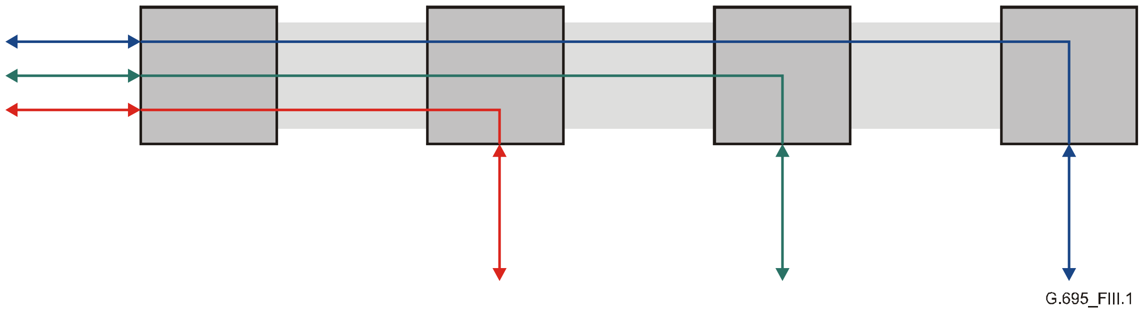

Figure III.1 – Simple example of linear black link topology

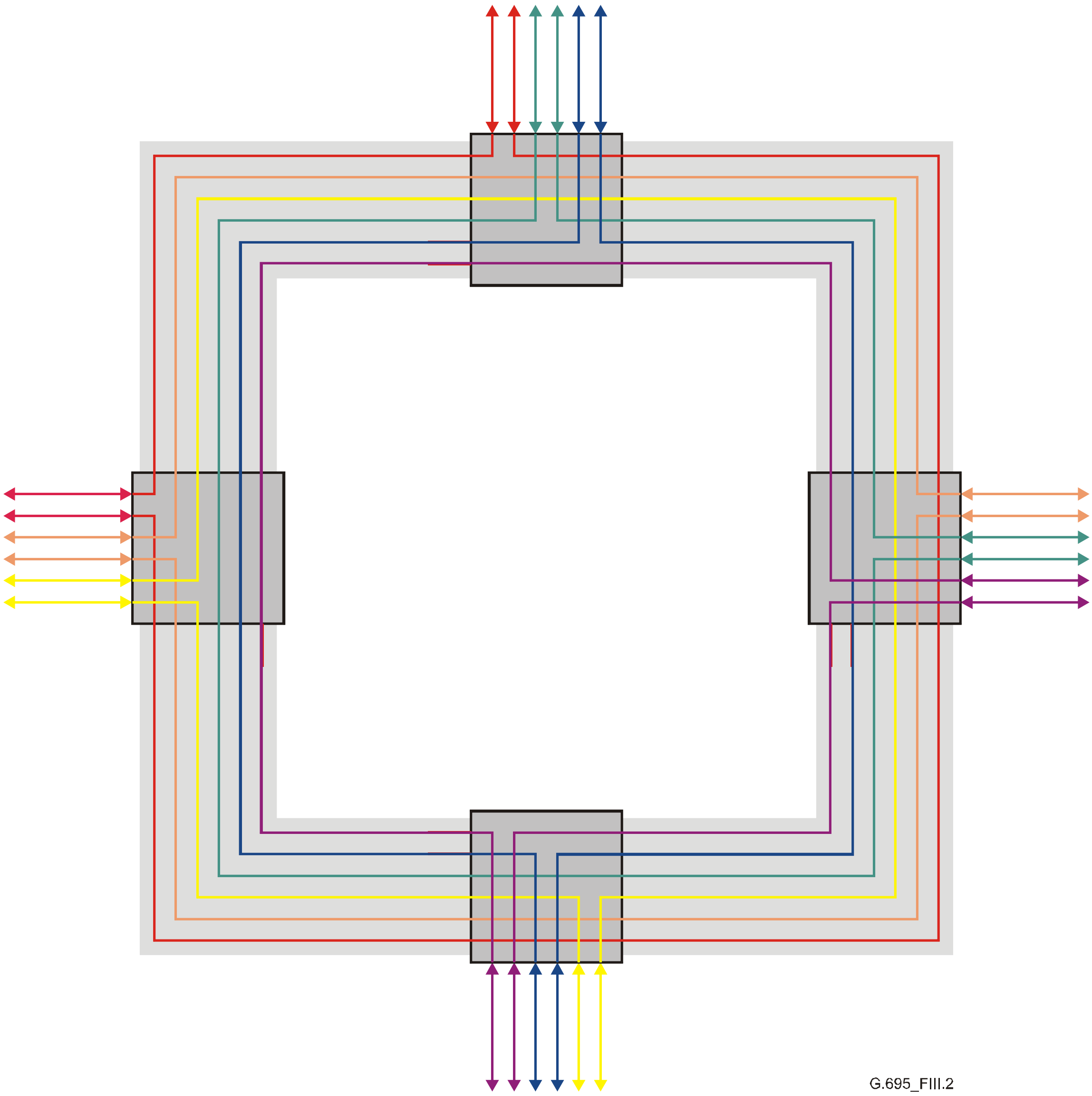

Figure III.2 – Complex example of ring black link topology

For some paths, it may be necessary to add some optical attenuation on the black link side of the S_S or R_S interface so that the minimum channel insertion loss requirement of the black link between S_S and R_S is met, without affecting the loss for other paths.

III.2 Mixed application codes

It is possible to use a mixture of different, but compatible, application codes on the same black link. For example, low loss paths may use S-C8S1-1D2 whilst high loss paths may use S-C8L1-1D2.

III.3 Protection

CWDM black link rings offer the possibility of protected optical paths. Protection may be implemented by several means, including:

a) Client-level protection, with the CWDM black link ring providing two physically diverse optical paths between a pair of clients. These two optical paths may or may not use the same CWDM wavelength.

b) Integrated protection, with the OADMs providing a single client interface and with protection switching within the OADM.

The characteristics of systems that provide protection switching are outside the scope of this Recommendation; however, the application codes in this Recommendation can be used in these systems as long as the optical path between S_S and R_S always complies with the requirements of the relevant application code.

Appendix IV

Parameter values for 16-channel NRZ 2.5G applications

(This appendix does not form an integral part of this Recommendation)

This appendix provides initial parameter values for 16-channel NRZ 2.5G applications. It is anticipated that, as the technology evolves, these values may need to be revised. See Tables IV.1 to IV.4 (also see Tables 8-7 to 8-10).

Table IV.1 – Physical layer parameters and values for multichannel interfaces for 16-channel NRZ 2.5G black box application C16S1-1D2

Parameter	Units	C16S1-1D2		
Wavelength block	nm	1311-1371	1391-1451	1471-1611
General information				
Maximum number of channels	–	16		
Bit rate/line coding of optical tributary signals	–	NRZ 2.5G		
Maximum bit error ratio	–	10^{-12}		
Fibre type	–	G.652.C or G.652.D		
Interface at point MPI-S_M				
Maximum mean channel output power	dBm	+3.5	+2.5	+1.5
Minimum mean channel output power	dBm	−4	−5	−6
Maximum mean total output power	dBm	+14.2		
Central wavelength	nm	1311 + 20 m, m = 0 to 3	1391 + 20 m, m = 0 to 3	1471 + 20 m, m = 0 to 7
Channel spacing	nm	20		
Maximum central wavelength deviation (Note)	nm	±6.5		
Minimum channel extinction ratio	dB	8.2		
Eye mask	–	STM-16 per G.957		
Optical path (single span) from point MPI-S_M to MPI-R_M				
Maximum attenuation	dB	8.5	7.5	6.5
Minimum attenuation	dB	3.5	2.5	1
Chromatic dispersion range				
– 1311 nm channel	ps/nm	–45 to +39		
– 1331 nm channel	ps/nm	0 to +81		
– 1351 nm channel	ps/nm	0 to +121		
– 1371 nm channel	ps/nm	0 to +160		
– 1391 nm channel	ps/nm		0 to +193	
– 1411 nm channel	ps/nm		0 to +221	
– 1431 nm channel	ps/nm		0 to +249	

Table IV.1 – Physical layer parameters and values for multichannel interfaces for 16-channel NRZ 2.5G black box application C16S1-1D2

Parameter	Units	C16S1-1D2		
– 1451 nm channel	ps/nm		0 to +278	
– 1471 nm channel	ps/nm			0 to +307
– 1491 nm channel	ps/nm			0 to +335
– 1511 nm channel	ps/nm			0 to +364
– 1531 nm channel	ps/nm			0 to +393
– 1551 nm channel	ps/nm			0 to +422
– 1571 nm channel	ps/nm			0 to +451
– 1591 nm channel	ps/nm			0 to +480
– 1611 nm channel	ps/nm			0 to +510
Minimum optical return loss at MPI-S_M	dB	24		
Maximum discrete reflectance between MPI-S_M and MPI-R_M	dB	−27		
Maximum differential group delay	ps	120		
Interface at point MPI-R_M				
Maximum mean channel input power	dBm	0	0	+0.5
Minimum mean channel input power	dBm	−12.5	−12.5	−13
Maximum mean total input power	dBm	+12.3		
Maximum optical path penalty	dB	1	1	1.5
Minimum equivalent sensitivity	dBm	−13.5	−13.5	−14
Maximum reflectance of optical network element	dB	−27		
NOTE – A system with ±7 nm maximum central wavelength deviation which is compliant with all other ITU-T G.695 parameter values of the relevant application code is transversely compatible for any applications covered by that code, except that it does not provide transverse compatibility with a ±6.5 nm system without joint engineering.				

Table IV.2 – Physical layer parameters and values for multichannel interfaces for 16-channel NRZ 2.5G black box application C16L1-1D2

Parameter	Units	C16L1-1D2		
Wavelength block	nm	1311-1371	1391-1451	1471-1611
General information				
Maximum number of channels	–	16		
Bit rate/line coding of optical tributary signals	–	NRZ 2.5G		
Maximum bit error ratio	–	10^{-12}		
Fibre type	–	G.652.C or G.652.D		

Table IV.2 – Physical layer parameters and values for multichannel interfaces for 16-channel NRZ 2.5G black box application C16L1-1D2

Parameter	Units	C16L1-1D2		
Interface at point MPI-S_M				
Maximum mean channel output power	dBm	+3.5	+1.5	−0.5
Minimum mean channel output power	dBm	−4	−6	−8
Maximum mean total output power	dBm	+13.4		
Central wavelength	nm	1311 + 20 m, m = 0 to 3	1391 + 20 m, m = 0 to 3	1471 + 20 m, m = 0 to 7
Channel spacing	nm	20		
Maximum central wavelength deviation (Note)	nm	±6.5		
Minimum channel extinction ratio	dB	8.2		
Eye mask	–	STM-16 per G.957		
Optical path (single span) from point MPI-S_M to MPI-R_M				
Maximum attenuation	dB	18	15.8	13.3
Minimum attenuation	dB	11	9	7
Chromatic dispersion range				
– 1311 nm channel	ps/nm	–95 to +82		
– 1331 nm channel	ps/nm	0 to +171		
– 1351 nm channel	ps/nm	0 to +257		
– 1371 nm channel	ps/nm	0 to +339		
– 1391 nm channel	ps/nm		0 to +408	
– 1411 nm channel	ps/nm		0 to +468	
– 1431 nm channel	ps/nm		0 to +528	
– 1451 nm channel	ps/nm		0 to +588	
– 1471 nm channel	ps/nm			0 to +649
– 1491 nm channel	ps/nm			0 to +710
– 1511 nm channel	ps/nm			0 to +771
– 1531 nm channel	ps/nm			0 to +832
– 1551 nm channel	ps/nm			0 to +894
– 1571 nm channel	ps/nm			0 to +956
– 1591 nm channel	ps/nm			0 to +1018
– 1611 nm channel	ps/nm			0 to +1080
Minimum optical return loss at MPI-S_M	dB	24		
Maximum discrete reflectance between MPI-S_M and MPI-R_M	dB	–27		
Maximum differential group delay	ps	120		

Table IV.2 – Physical layer parameters and values for multichannel interfaces for 16-channel NRZ 2.5G black box application C16L1-1D2

Parameter	Units	C16L1-1D2		
Interface at point MPI-R$_M$				
Maximum mean channel input power	dBm	−7.5		
Minimum mean channel input power	dBm	−22	−21.8	−21.3
Maximum mean total input power	dBm	+4.5		
Maximum optical path penalty	dB	1	1.5	2
Minimum equivalent sensitivity	dBm	−23	−23.3	−23.3
Maximum reflectance of optical network element	dB	−27		
NOTE – A system with ±7 nm maximum central wavelength deviation which is compliant with all other ITU-T G.695 parameter values of the relevant application code is transversely compatible for any applications covered by that code, except that it does not provide transverse compatibility with a ±6.5 nm system without joint engineering.				

Table IV.3 – Physical layer parameters and values for multichannel interfaces for 16-channel NRZ 2.5G black box application B-C16S1-1D2

Parameter	Units	B-C16S1-1D2		
Wavelength block	nm	1311-1371	1391-1451	1471-1611
General information				
Maximum number of channels	–	8 + 8		
Bit rate/line coding of optical tributary signals	–	NRZ 2.5G		
Maximum bit error ratio	–	10^{-12}		
Fibre type	–	G.652.C or G.652.D		
Interface at point MPI-S$_M$				
Maximum mean channel output power	dBm	+3.5	+2	+1.5
Minimum mean channel output power	dBm	−4	−5	−6
Maximum mean total output power	dBm	+11.8		
Central wavelength	nm	1311 + 20 m, m = 0 to 3	1391 + 20 m, m = 0 to 3	1471 + 20 m, m = 0 to 7
Channel spacing	nm	20		
Maximum central wavelength deviation (Note)	nm	±6.5		
Minimum channel extinction ratio	dB	8.2		
Eye mask	–	STM-16 per G.957		

Table IV.3 – Physical layer parameters and values for multichannel interfaces for 16-channel NRZ 2.5G black box application B-C16S1-1D2

Parameter	Units	B-C16S1-1D2		
Optical path (single span) from point MPI-S_M to MPI-R_M				
Maximum attenuation	dB	8.5	7.5	6.3
Minimum attenuation	dB	3.5	2.5	1
Chromatic dispersion range				
– 1311 nm channel	ps/nm	–45 to +39		
– 1331 nm channel	ps/nm	0 to +81		
– 1351 nm channel	ps/nm	0 to +121		
– 1371 nm channel	ps/nm	0 to +160		
– 1391 nm channel	ps/nm		0 to +193	
– 1411 nm channel	ps/nm		0 to +221	
– 1431 nm channel	ps/nm		0 to +249	
– 1451 nm channel	ps/nm		0 to +278	
– 1471 nm channel	ps/nm			0 to +307
– 1491 nm channel	ps/nm			0 to +335
– 1511 nm channel	ps/nm			0 to +364
– 1531 nm channel	ps/nm			0 to +393
– 1551 nm channel	ps/nm			0 to +422
– 1571 nm channel	ps/nm			0 to +451
– 1591 nm channel	ps/nm			0 to +480
– 1611nm channel	ps/nm			0 to +510
Minimum optical return loss at MPI-S_M	dB	24		
Maximum discrete reflectance between MPI-S_M and MPI-R_M	dB	−27		
Maximum differential group delay	ps	120		
Interface at point MPI-R_M				
Maximum mean channel input power	dBm	0	−0.5	+0.5
Minimum mean channel input power	dBm	−12.5	−12.5	−12.8
Maximum mean total input power	dBm	+9.5		
Maximum optical path penalty	dB	1	1	1.5
Minimum equivalent sensitivity	dBm	−13.5	−13.5	−13.8
Maximum reflectance of optical network element	dB	−27		
NOTE – A system with ±7 nm maximum central wavelength deviation which is compliant with all other ITU-T G.695 parameter values of the relevant application code is transversely compatible for any applications covered by that code, except that it does not provide transverse compatibility with a ±6.5 nm system without joint engineering.				

Table IV.4 – Physical layer parameters and values for multichannel interfaces for 16-channel NRZ 2.5G black box application B-C16L1-1D2

Parameter	Units	B-C16L1-1D2		
Wavelength block	nm	1311-1371	1391-1451	1471-1611
General information				
Maximum number of channels	–	8 + 8		
Bit rate/line coding of optical tributary signals	–	NRZ 2.5G		
Maximum bit error ratio	–	10^{-12}		
Fibre type	–	G.652.C or G.652.D		
Interface at point MPI-S_M				
Maximum mean channel output power	dBm	+3.5	+1.5	−0.5
Minimum mean channel output power	dBm	−4	−6	−8
Maximum mean total output power	dBm	+11.6		
Central wavelength	nm	1311 + 20 m, m = 0 to 3	1391 + 20 m, m = 0 to 3	1471 + 20 m, m = 0 to 7
Channel spacing	nm	20		
Maximum central wavelength deviation (Note)	nm	±6.5		
Minimum channel extinction ratio	dB	8.2		
Eye mask	–	STM-16 per G.957		
Optical path (single span) from point MPI-S_M to MPI-R_M				
Maximum attenuation	dB	18	15.8	13.3
Minimum attenuation	dB	11	9	7
Chromatic dispersion range				
– 1311 nm channel	ps/nm	–95 to +82		
– 1331 nm channel	ps/nm	0 to +171		
– 1351 nm channel	ps/nm	0 to +257		
– 1371 nm channel	ps/nm	0 to +339		
– 1391 nm channel	ps/nm		0 to +408	
– 1411 nm channel	ps/nm		0 to +468	
– 1431 nm channel	ps/nm		0 to +528	
– 1451 nm channel	ps/nm		0 to +588	
– 1471 nm channel	ps/nm			0 to +649
– 1491 nm channel	ps/nm			0 to +710
– 1511 nm channel	ps/nm			0 to +771
– 1531 nm channel	ps/nm			0 to +832
– 1551 nm channel	ps/nm			0 to +894

Table IV.4 – Physical layer parameters and values for multichannel interfaces for 16-channel NRZ 2.5G black box application B-C16L1-1D2

Parameter	Units	B-C16L1-1D2		
– 1571 nm channel	ps/nm			0 to +956
– 1591 nm channel	ps/nm			0 to +1018
– 1611 nm channel	ps/nm			0 to +1080
Minimum optical return loss at MPI-S_M	dB	24		
Maximum discrete reflectance between MPI-S_M and MPI-R_M	dB	−27		
Maximum differential group delay	ps	120		
Interface at point MPI-R_M				
Maximum mean channel input power	dBm	−7.5		
Minimum mean channel input power	dBm	−22	−21.8	−21.3
Maximum mean total input power	dBm	+1.5		
Maximum optical path penalty	dB	1	1.5	2
Minimum equivalent sensitivity	dBm	−23	−23.3	−23.3
Maximum reflectance of optical network element	dB	−27		
NOTE – A system with ±7 nm maximum central wavelength deviation which is compliant with all other ITU-T G.695 parameter values of the relevant application code is transversely compatible for any applications covered by that code, except that it does not provide transverse compatibility with a ±6.5 nm system without joint engineering.				

Bibliography

[b-ITU-T G-Sup.39] ITU-T G-series Recommendations – Supplement 39 (2006), *Optical system design and engineering considerations*.

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Printed in Switzerland
Geneva, 2010